MECHANICAL PROCESSES

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MECHANICAL PROCESSES

MECHANICAL PROCESSES

A PRACTICAL TREATISE ON WORKSHOP APPLIANCES AND OPERATIONS FOR THE INSTRUCTION OF MIDSHIPMEN

AT THE

U. S. NAVAL ACADEMY

BY

JOHN K. BARTON

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types of American tools and machinery, and to Mr. O. Z. Howard of the Engineering Department for his interest and care in the drawings accompanying the text.

JOHN K. BARTON,
Commander, U. S. Navy.

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In the preparation of this book the following publications have been consulted:

The Journal American Society of Naval Engineers.
Machinery Specifications, U. S. Navy.
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Metallurgy, by E. L. Rhead.
Metals, by Huntingdon and McMillan.
Mechanical Engineering, by W. J. Lineham.
Pattern-Making, by I. McK. Chase.
Pattern-Making, by P. S. Dingey.
Forge Practice, by J. L. Bacon.
Machine Tools and Workshop Practice, by Alfred Parr.
Modern Machine Shop Tools, by W. H. Van Dervoort.
Workshop Appliances, by C. P. Shelley.

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CHAPTER I.

CONSTRUCTION MATERIAL USED BY THE ENGINEER.

Before going into the details of the varied operations employed in mechanical engineering, some of the different materials used will be briefly considered, their properties, method of production, and to some slight extent the metallurgical principles involved.

These materials used are as follows:

1. Cast iron.	4. Copper.	7. Brasses.
2. Wrought iron.	5. Zinc.	8. Bronzes.
3. Steel.	6. Tin.	9. Wood.

Metals.—The principal chemical elements employed in engineering metallurgical operations, and the elements contained in the *ore* chemically combined with the metal are: Carbon (C), oxygen (O), sulphur (S), chlorine (Cl), phosphorus (P), silica (Si), manganese (Mn), and fluorine (Fl). The most common compounds in which metals are found in the ores are:

Oxides: Metal and oxygen in combination.	Iron, copper, etc.
Carbonates: Metal, carbon, and oxygen.	Iron, copper, etc.
Sulphides: Metal and sulphur.	Copper, lead, etc.
Chlorides: Metal and chlorine.	Copper, silver, etc.
Phosphates: Metal, phosphorus, and oxygen.	Lead, etc.
Silicates: Metal, silica, and oxygen.	Copper, zinc, nickel, etc.
Fluorides: Metal and fluorine.	Aluminum, etc.

The percentage of metal in the ore necessary to make it profitable in working, depends upon the value of the metal obtained from the ore, and the form in which it is found; for instance, a slight percentage of gold per ton of ore forms a practicable working operation, while iron ore containing less than 25 percent is not profitable. Iron pyrites contains 46 percent of iron, but the sulphur with which it is combined is extremely difficult to eliminate, fur-

nishing a very inferior and unreliable quality of iron, the ore is consequently used in the manufacture of other substances, notably vitriol.

Iron.—Iron is used in three forms: cast iron, wrought iron, and steel. Laying aside for the moment the difference in the physical characteristics of these three metals, the main chemical difference between cast and wrought iron is that the former contains a large proportion of carbon and silicon, while the latter has practically none. Steel takes an intermediate position as regards carbon and should be as free as possible from silicon. Cast iron may contain as high as five percent of carbon; wrought iron seldom exceeds one-fourth of one percent, and may fall as low as .05 of one percent. Steel varies between the two and may run as high as 1.5 percent. In cast iron the carbon is combined and is also found in a *graphitic state,* interposed between the particles. The properties of both iron and steel are modified by the amount and manner in which the carbon is held. Combined carbon hardens the metal, lowers the melting point, destroys malleability and the welding property, and increases brittleness.

Silicon in varying amounts is present in cast iron and renders it more fusible, weak, and brittle.

Manganese in cast iron is beneficial from its power of removing oxygen and sulphur, and the production of a fluid slag. Pig iron containing from 10 to 20 percent of manganese is known by the trade name of *spiegel-eisen,* and is much used in steel-making. The presence of *sulphur* impairs the quality of both iron and steel; it produces *red shortness,* that is, the metal cracks under the hammer at, and above, a red heat, hence it can not be worked hot. It is difficult to remove, but the presence of manganese neutralizes the effect to some extent. Phosphorus present in iron acts in the reverse manner to sulphur, producing *cold shortness,* that is, it cracks and breaks when worked cold or under shock. The metal is weaker and more brittle. The presence of *nickel* increases toughness and reduces the tendency to corrosion. In steel-making, *nickel steel* is much used for high-grade machinery forgings and armor-plate. Aluminum is added to cast iron to produce finer grained and stronger castings.

Iron Oxides.—In the metallurgy of iron, the three oxides of im-

portance are *ferrous oxide* (FeO), ferric oxide (Fe_2O_3), and *magnetic oxide* (Fe_3O_4).

Ferrous Oxide.—This oxide does not occur free but it is met in combination, forming salts, as ferrous sulphate (copperas). It is also a constituent of many slags.

Ferric Oxide.—This occurs in iron ores and in the common form of iron rust.

Magnetic oxide of iron is found as *magnetite,* and also found in the scale which is formed on red hot iron when exposed to the air.

Iron Ores.—The principal iron ores are magnetite, red and brown hematite, specular iron ore, spathic ore, clay ironstone, and black-band ore.

Magnetite (Fe_3O_4) consists of iron and oxygen, and when pure contains 72 percent of metal. One variety of the ore is known as the *lodestone,* possessing the quality of attracting iron and steel.

Red hematite (Fe_2O_3) derives its name from its red color and is quite pure, furnishing iron of the best quality.

Specular iron ore is another ferric oxide, similar in composition to red hematite, but of different appearance. It forms crystalline masses of a steel-grey color and lustrous.

Brown hematite ($2Fe_2O_3 + 3H_2O$) is a hydrated ferric oxide, and contains the same oxide of iron in a chemical combination with water. When pure it contains 60 percent of iron.

Spathic iron ore ($FeCO_3$), so called on account of its sparry appearance, is composed of ferrous oxide combined with carbonic acid. It is of an ashen-grey color, streaked with white, and contains about 48 percent of iron. It usually contains manganese, which renders it valuable in the manufacture of steel, and is known at times as *steel ore.*

Clay Ironstone.—This ore contains iron in the form of a carbonate, and is composed of iron, oxygen, and carbonic acid intimately mixed with clay. It is stony in appearance and varies in color through shades of grey, slate blue and brown. The pig iron from this ore is, as a rule, less pure than the preceding.

Black band ore is similar to clay ironstone and differs from it only in the admixture of coaly matter, sometimes amounting to one-fifth the ore.

Iron pyrites (Fe_2S) is composed of iron and sulphur in chemical combination, 46.5 parts of the former to 53.5 parts of the latter. The extraction of iron from this mineral, after burning, has not been very successful, but it is largely used as the source of sulphur in the manufacture of sulphuric acid.

Fuels.—The different operations by which the metal is separated from the ore by fusion are known as *smelting,* and the fuels used in the reduction of iron are charcoal, coal, and coke, while in the operations of steel-making in open-hearth furnaces, annealing furnaces, etc., fuel gas is largely employed.

Charcoal is produced when wood is gradually heated out of contact with air, undergoing a destructive distillation, and during the operation, water and the other volatile compounds, are driven out and free carbon separated. The result is charcoal, consisting of the fixed carbon of the wood with some hydrogen and oxygen. Charcoal may be prepared by sawing the wood into suitable lengths and piling it uniformly in large stacks about a center, forming a chimney, and covering the whole with sod or earth. This furnishes an elastic cover and sufficiently impervious to air. The fagots in the center are ignited and, after the pile has thoroughly started burning, the central opening for a chimney is closed. From time to time small openings are judiciously made in various parts of the cover to admit a little air to maintain the combustion of the volatile parts, and to draw the heat in the direction desired. This is continued until the whole mass is charred. Care is necessary not to admit an excess of air to avoid burning the charcoal. Charcoal is also obtained by charring the wood in retorts, heated externally, when it is desired to produce also pyroligneous acid and tar.

Coal.—Soft coal, burning with a greater or less amount of heavy smoke and smoky flame resembling pitch, is termed *bituminous coal.* Bituminous coal is divided into *caking* and *non-caking* coal. The former burns freely and with a long flame. It is of a dull lustre, breaks with a crystalline fracture, and is hard and dense. This class is represented by *splint* and *cannel* coal.

Caking coal comprises the various bituminous steaming coal and gas coal. It ignites easily, burns freely with quite an evolution of smoke; is friable and soft, cakes easily, and is known under the general name of soft coal. Another form of bituminous coal

is that used at the blacksmith's forge. It fuses when heated, swelling and forming a pasty mass which is converted into coke. Bituminous coal is not used in the manufacture of iron on account of its caking qualities, softness, and the contained impurities, such as sulphur, etc. These defects are eliminated by converting the coal into coke.

Anthracite coal has a brilliant black, metallic appearance, hard, brittle, and crystalline in fracture. Anthracite burns with difficulty, requiring a strong draft, and is non-caking.

Impurities in Coal.—The quantity and nature of *ash* varies greatly in the different classes of coal, depending on the quality of the coal and its chemical composition. *Clinker* is a fusible compound formed with the ash at the temperature of the furnace and tends to block the grate, and prevents the proper access of air.

Sulphur occurs in coal as *iron pyrites,* and in the form of sulphates. Coal containing much sulphur is not fitted for use in iron manufacture when the coal comes in contact with the metal, producing an impurity in the iron called *red-shortness.*

Phosphorus to a greater or less amount is always found in coal. In the manufacture of iron and steel, the presence of phosphorus produces *cold-shortness* in the material.

Chlorine when present in fuel is objectionable for boiler plants, as a rapid corrosion ensues in the vicinity of damp ashes.

Coke.—Many of the impurities of coal preventing its use in certain operations may be eliminated by coking. Coke in relation to coal is analagous to that of charcoal to wood, and consists of the fixed carbon and inorganic constituents of the coal. It is manufactured from bituminous coal by subjecting it to a sufficiently high temperature, to deprive it of its volatile constituents. The volatile matters are sometimes utilized, but are generally wasted, except where the coke is considered a secondary product, as in the making of illuminating gas.

Coking is carried on by either of three methods: in open heaps, in coke ovens, or in retorts. The first method is wasteful and rarely employed; the second is more economical and the one generally adopted when coke is the primary product, and produces a strong coke, well adapted for furnace work. The third method is the

best, where illuminating gas is manufactured, and the only one practicable for that purpose.

Gas Fuel.—For heating, smelting, annealing furnaces and other purposes, gas is largely employed as a fuel, and obtained by three methods, the products being known as *air gas* or *producer* gas, water gas and natural gas.

Producer Gas.—If a limited supply of air is passed through a deep mass of carbonaceous material, such as bituminous coal, a decomposition ensues, the oxygen is converted into carbonic oxide (CO) and mixes with the nitrogen of the air, a slight quantity of

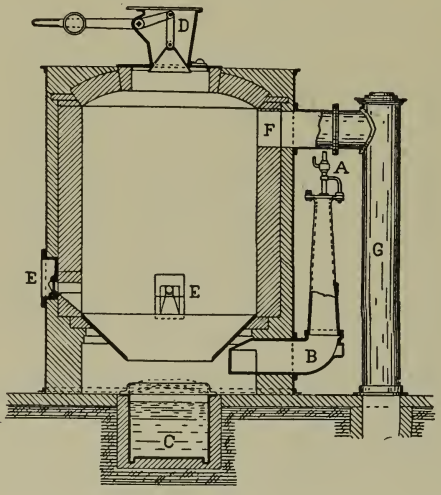


FIG. 1.

carbonic acid formed, together with the hydrogen and hydrocarbons, the whole constituting producer gas. Any moisture present in the entering air is also decomposed into hydrogen and carbonic oxide, thus increasing the richness of the gas. The fixed carbon, as well as the volatile matter, is thus converted into gas, the only residue being the ash. In almost all metallurgical operations, the fuel used in the producer is rich bituminous coal, but for some special cases, as for gas engines, hard coal is used, as the gas contains but little tarry vapor.

A type of gas producer, of which there are many modifications on the same general principle, is shown in Fig. 1. Coal is intro-

duced through the hopper *D*, fitted with a cover, while the cone forms the valve at the bottom. *A* is the steam injector, and *B* the air port; high pressure steam enters through *A* and aspirates the air, and the two combined are forced through the incandescent fuel. If air is used alone there is a considerable quantity of inert, incombustible nitrogen in the resulting gas, while with steam alone nearly all the product is combustible, but heat is absorbed by the decomposition, and the temperature falls too low, hence a combination of steam and air is used in modern producers. The fuel gradually sinks as combustion proceeds and fresh fuel is added; the mixed air and steam rising through the burning fuel at the bottom forms a combustible gas which is considerably enriched and increased as it passes through the upper layers of coal, converting this latter into coke by its heat. This gas makes its exit through *F*, into the down-commer *G*, and thence to the furnace. *EE* are openings for the insertion of clinker bars. *C* is the water bottom filled with water to the depth of a few inches below the level of the entering air. The clinker formed becomes disintegrated on reaching the water, and with the ashes can be readily removed through a side well without interfering with the operation of the producer.

Water Gas.—When steam is passed over incandescent carbon, preferably in the shape of coke or anthracite coal, a mixture of nearly equal parts of carbonic oxide and hydrogen is produced, forming the mixture called *water gas.*

Natural Gas.—In the district just west of the Alleghenies in Pennsylvania, West Virginia, and Ohio, natural gas is largely used for furnace and heating purposes. Natural gas consists mainly of marsh gas and is burnt directly with air regenerated in the usual manner, but of late the supply has been decreasing.

Refractory Materials.—These substances are employed for lining furnaces and are consequently required to resist the destructive action of the intense heat, the corrosive action of the metallic oxides, and the chemical affinities which will be brought into action between the body of the furnace and the material heated. The substances principally used are *silica, alumina, lime,* and *magnesia.*

Fire-Clay.—This substance, a hydrated silicate of alumina (alumina, silica, and water), is the most important and most general substance used. Silicate of alumina is infusible at the ordinary

temperature, and any excess of silica renders it more refractory. In *burning* the clay, the water is expelled and a hard *anhydrous* substance results, incapable thereafter of taking up water. In this process, contraction ensues, and in using the material allowance must be made; with fire-bricks, by increasing the dimensions; and in crucibles and for other purposes, by mixing with the clay some substances which will expand in a like degree, or at least remain neutral, viz., silica, sand, flint, burnt clay, coke dust and graphite. To test a fire-brick for its refractory quality, heat it strongly, and if, after cooling, the edges remain perfectly sharp, the material is refractory up to the temperature tested.

Ganister.—This is another siliceous material and largely used for lining *converters* in the Bessemer process of steel-making. It is a type of sandstone in which the grains are cemented by clayey matter. When ground fine and mixed with water it binds well by pressure, thus giving the advantage of forming the lining, and burning it in place in the furnace. In burning it, there is but little expansion or contraction.

Sand.—This material is much used for making the bottoms of furnaces such as the regenerative open-hearth steel furnaces. It becomes mixed with the iron oxides and forms a durable lining, the sand employed being highly siliceous.

Basic Linings.—The materials previously mentioned are *siliceous,* or acid in character, and would be unsuitable under certain circumstances; for instance, they would flux away in continuous heating with metallic oxides, and another important reason, it is not possible in steel-making by the Bessemer and open-hearth process to remove the phosphorus. To utilize a greater number of grades of iron, a *basic lining* is introduced, that is, a lining composed of metallic oxides. Of these the principal are *lime, magnesia,* and *alumina. Lime* is plentiful, extremely infusible at any temperature available, but it absorbs moisture, forms a hydrate, and crumbles to pieces, hence it is utilized only for small operations, as with the oxy-hydrogen blow-pipe.

Magnesia.—This substance, unlike lime, does not absorb water, and in the form of *dolomite,* a mountain lime stone, composed of carbonates of lime and magnesia, can be strongly calcined, leaving a mixture of lime and magnesia which can be reheated and cooled

as often as required without crumbling. It has no binding qualities, however, and for use it is ground and mixed with about 10 percent of boiled tar, made into a *slurry* and rammed into position around a central core as, for instance, in a Bessemer converter. The tar is decomposed on heating and the remaining carbon serves to cement the lining firmly together. This substance is generally known as the *basic lining.*

Other refractory materials are *bauxite,* a mixture of hydrated alumina and ferric oxide, and in addition to those given, several other substances containing large proportions of the oxides of iron Fe_2O_3 and Fe_3O_4 are used in making the bottoms and sides of puddling furnaces in the conversion of cast into wrought iron. In addition to their refractory qualities they aid in refining the iron.

Plumbago or graphite is infusible and is used extensively in making crucibles for metal-melting purposes. They have a longer life than clay crucibles and can resist sudden changes of temperature, so that they can be used frequently over and over again.

Physical Properties of Metals.—The properties on which the usefulness of metal depends are: *Specific gravity,* or the weight of the metal compared with an equal bulk of water; *hardness; toughness,* or the resistance offered to fracture by bending or twisting; *tenacity,* or the resistance offered by the metal to being torn asunder or stretching; *malleability,* the capability of being hammered or rolled into thin sheets; *ductility,* the property of being drawn out into wire; *fusibility,* the property of becoming liquid when heated; *elasticity,* or the amount of force which can be resisted by the metal without a permanent deformation or *set* being produced; *expansion* by heat; resistance to *atmospheric* and *chemical* action; *conductivity* for electricity and heat; and the effect on the properties of other metals when mixed with them.

Elongation is the extent to which a metal elongates prior to fracture, and is a matter of extreme importance in engineering material. A tough metal usually shows considerable elongation, while a hard brittle metal shows but little increase in length.

Elastic Limit.—If a bar of metal be held vertically, firmly fixed at one end, and increasing weights gradually applied to the other end, the bar will increase in length, and at first, if the weights are removed, the bar will return to its original length. The bar is then

perfectly elastic, the *extension* being proportional to the load applied. If the load is further increased a point will be reached when the extension will increase more rapidly than the load, and the bar, after the removal of the load, will be found permanently stretched. The point at which the ratio of the load to the extension ceases to be constant, and beyond which a *permanent set* or distortion is produced is called the *elastic limit* of the metal. Beyond this point the distortion produced by further additions to the load becomes greater and greater and, after an extension in proportion to the ductility of the metal, it finally pulls apart under the stress. The load at which rupture takes place is known as the *tensile strength,* and is expressed in tons or pounds per square inch required to pull apart a one-inch square bar. The extension at the moment of rupture is also measured on the testing machine, the specifications of material requiring a certain percentage of elongation in a given length, and also the percentage of the contraction of area at the point of rupture.

Welding is the property possessed by some metals of uniting without the use of solder, when pressed together under certain conditions. *Conductivity,* or the property whereby heat is transmitted through the mass of the body itself, is variable in metals, and those metals which are the best conductors of heat are also the best conductors of electricity.

Strains-Stresses.—As shown above, in a body subjected to the action of forces or loads certain deformations are produced. These deformations, or the result of the applied forces, are termed *strains,* and the forces by which they are produced are called *stresses.*

Reduction of Iron Ores.—The ores go through a preliminary process of grading, usually at the mine, calcination or roasting in open-air heaps, or kilns, to expel all volatile constituents, as water, carbonic acid, etc., and getting them in shape for making up the charge for the blast furnace. This make up, or proportions of the charge, depend upon the character of the ore, the fuel, the flux, size and method of working the furnace, and character of the cast iron required.

Charcoal as fuel is the least detrimental to the product, coke and anthracite coal make good iron, while bituminous coal has the least

merit, and is used only for cheap grades of iron, as the proportion of sulphur in the fuel is objectionable. Limestone is the usual flux.

Fluxes.—To render the ores more fusible and thus enable the metal to separate more easily from the useless portion during fusion, some substances are mixed with the ore and reducing agents in the furnace, which either melt and dissolve the infusible earthy matters in the ore, or by combining with them in the furnace, form a substance which is fusible at the temperature used. The substances added for the above purpose are known as *fluxes,* while the useless earthy portion of the ore combined with the flux and forming a fusible body, is called *slag* or *cinder.* The earthy matters to be removed are either earthy metallic oxides and carbonates, *basic* in character, or those containing silica, such as quartz sand, and are *acid* in character. When the ore is siliceous, lime and clay are added as flux; calcareous ores require silica and alumina; and clay ores, sand and limestone. In general, an acid is employed as a flux for a basic ore and a base for an acid.

The Blast Furnace.—The modern form of the blast furnace, illustrated in Fig. 2, is a type of those found in large American iron and steel plants. The walls of the furnace are double and separated by a space *AA* filled with powdered coke, loam or sand, thus taking up the unequal expansion and contraction. The inner wall or lining *BB* is constructed of some refractory substance, generally fire-brick blocks, well fitted so as to ensure perfect setting and uniformity in the lines of the furnace. The outer walls *CC* may be made of red brick, hard burned. The structure should be either banded with hoop iron for strength or jacketed with sheet iron.

The furnace gradually widens from the cylindrical part at the bottom and then contracts. The part included between the widest part of the furnace and the hearth *E* is called the *boshes,* and the part above is called the *throat.* The *tuyeres* or nozzles opening into the hearth through which hot air is blown for the blast are shown at *FF.* These tuyeres completely surround the *hearth.* Air is supplied by the blowers to the *blast-main G,* surrounding the lower part of the furnace, an air pipe lined with fire-brick, and to which each tuyere is connected. Each tuyere connecting-pipe is fitted with a valve by means of which the air-supply is regulated. The tuyeres are kept cool by the circulation of water around them,

either by means of a pipe coil or in their hollow walls, as shown at *H*.

The life of the furnace depends largely upon the preservation

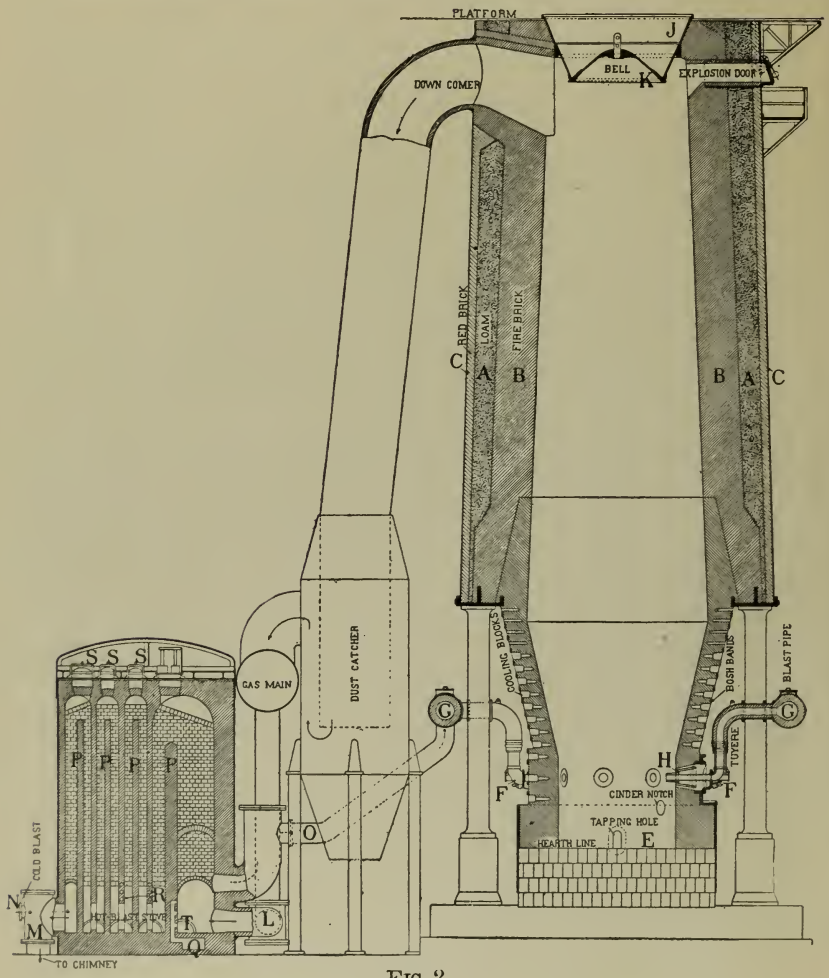


FIG. 2.

of the lines about that part where the charge is melted, i. e., from the hearth to the upper part of the boshes. Frequently *bosh plates* are employed as in the furnace illustrated. These are water-cooled

plates set in the brick-work and prevent change in the configuration of the boshes occasioned by the abrasion and melting action of the charge. The height of the furnace in modern American installations is from 90 to 100 feet, while the blast pressure is usually 15 pounds per square inch.

The slag passes out through a *slag hole*, or cinder notch, in the furnace wall. The metal is tapped out by means of the *tap hole* at the bottom of the dam, or the bottom of the hearth, and kept closed by a lump of clay held on to the end of a bar and forced into it. When the furnace is tapped this clay plug is broken away by a pointed bar and the metal allowed to flow out. *JK* is the *cup and cone* arrangement for closing the top of the furnace, and consists of a hollow cast iron cone made in sections and secured to the throat, forming the *cup*. This opening is closed by the *cone*, supported from one end of a lever, while the other has a counterpoise weight, permitting it to be lowered and raised easily for throwing in the furnace charges.

The charge, consisting of ore, flux, and fuel, is raised to the charging door by steam, hydraulic, pneumatic elevators or inclined planes. The gases produced in the furnace during the operation of reduction pass out the side, under the cone, into a large iron pipe, *down-commer*, and are led away to be burnt under boilers, stoves, regenerators, etc.

Operation.—Since rapid increase of temperature would crack the furnace lining, the furnace is first heated and the walls dried slowly for several days, when the fires are gradually increased by the addition of fuel ore and slag until the furnace becomes hot enough, when the proportions of ore and flux are increased; the blast finally turned on and *smelting* commenced. The proportionate quantity of ore and flux are further increased, and in a few weeks the furnace is producing its maximum quantity of metal.

In putting the furnace out of blast, which may not be for months, the same precautions are observed in cooling it down, the proportion of ore is gradually decreased and the limestone flux increased until, when the fires have burnt out, the contents of the furnace are burned lime, and the furnace is not opened until it is cold.

The Charge.—The air supplied is heated to a temperature as high as 1100° to 1300° Fah., on account of the economy in fuel, the lowering of the fusion zone, the greater regularity in the working of the furnace, and the power of holding it more under control.

The charging of the furnace is conducted at regular intervals, and the metal accumulates on the hearth until it is full, when it is tapped, the metal running out in channels which feed open moulds in a sand bed. The castings in the moulds are called *pigs* and their commercial size is about 4 feet long and 4 by 4 inches in section.

Blast furnace slag, as previously mentioned, flows through the slag notch and is disposed of in various ways. The harder kinds are used for mending roads, for levelling, for ballast, and when suitable for moulding into slabs or bricks, it is used for some building purposes.

Blast stoves are either of iron or brick, the latter on the principle of the Siemens' regenerative system. The gases from the blast furnace are burnt in the blast stoves, and the products of the combustion drawn through brickwork, thus giving up their heat to it as they pass out to the smokestack. After the brickwork is heated, the gases are switched off to a second stove, and the air-blast passed through the heated stove in a direction opposite to the former current, thus attaining the temperature of the stove before entering the blast furnace. Two or more stoves are worked alternately, one being heated up by the blast-furnace gases, while the other is employed in giving up its heat to the entering blast.

The Whitwell Stove.—One of the simplest forms of the blast stove is shown in Fig 2; *L* is the gas valve which permits the furnace gas to enter from the gas flue; *Q* the air inlets for the combustion of the gases; *M*, the chimney valve; *N* is the cold blast pipe connection; *O*, the hot-blast main; *SS*, cleaning-holes; *PP*, firebrick partitions; the openings, *R*, at the bottom of the first and third partitions are for the purpose of admitting a further quantity of air to complete the combustion of the gases.

In its operation the waste gases from the furnace enter through the gas main *L* into the stove, where they are burnt by the admission of air through the inlets *Q*; the products of combustion then pass out through the chimney valve and chimney flue after giving up nearly all their heat to the brickwork in their passage through

the stove. As soon as the stove has been heated to a maximum, the gas supply, air and chimney valves are closed, the valve *N* on the cold-blast main is opened, together with the valve on the hot-blast main leading from the stove to the furnace. The stoves should be placed as near the furnace as practicable in order that the blast may retain as much of its heat as possible.

Wrought or Malleable Iron.—The usual definition given to wrought iron, is iron capable of being forged and worked at red heat, incapable of taking a temper or hardening by heating and quenching, and is limited to the metal obtained in the *direct process* from the ore, or indirectly through the *puddling furnace.*

In the *direct process* the malleable iron is extracted from the ore in one operation, whereas in the *indirect* method the ore is first

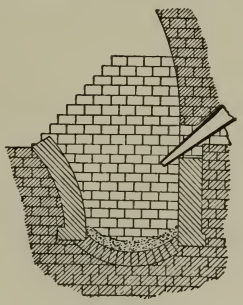


FIG. 2a.

reduced in the blast furnace, run out into pigs, *puddled,* hammered, rolled, reheated, and finally finished in the rolls as bar or sheet metal.

Direct Process.—The iron oxides can be reduced by carbon or carbonic oxide at a low red heat, and by allowing the oxide of iron to pass into the slag, carburization is prevented and the earthy matter separated. This slag is very fusible and mixed in with the reduced iron forms a pasty mass which is lifted and held before the tuyeres for a few minutes, taken under a hammer, the slag is expelled or squeezed out, and the small particles of iron welded together into a flat square mass of malleable iron called a *bloom.* Very rich ores containing not less than 50 percent of iron can only be used, if economy is desired. The fuel required is charcoal. This was the method employed in the earliest history of iron pro-

duction, and various modern direct processes on the same general principle are employed, but they are subject to the general objection that a large portion of the iron escapes into the slag, while in the blast furnace the slag is practically free from iron, and the fuel consumption economical.

The *Catalan process* of Spain is a typical example of the direct process. The hearth or forge in which the reduction is effected, Fig. 2a, is approximately a rectangular trough, one side of which curves outwards at the top, and on this sloping side the ore and fuel is introduced from time to time. On the opposite side is a tuyere pipe, and so supported that its inclination to the bottom of the hearth can be varied, as the ability to vary the direction of the blast greatly affects the success of the operation. The slag is removed by means of a tap hole at the bottom, the hole also being utilized to introduce a bar for lifting up the mass of iron when the process is completed.

Indirect Method.—In this process, by which the wrought iron of commerce is generally made, pig iron is passed through a process of refining and puddling and worked into the commercial condition by hammering and rolling. In this treatment the carbon, manganese, silicon, and phosphorus are largely removed by oxidation, together with a part of the sulphur.

Two distinct methods are employed in obtaining the desired result, namely, *open-fire or hearth fineries,* when the pig is melted and decarburized in a shallow hearth by the blast from an inclined tuyere, and the reverberatory or *puddling* furnace, when the same method is used on the bed of a reverberatory furnace. The reactions are the same in both cases, the carbon in the graphitic state passes first into the combined state, then into carbonic oxide either by the oxidizing effect of the blast directly, or by the action of the iron oxides dissolved in the slag. These oxidizing agents are introduced in the finery with the pig in the shape of red hematite, hammer scale, tap cinder, etc. When using these substances they must be brought into intimate contact with the metal by mixing them together when the charge is semi-fluid.

Briefly and generally the working of an open-fire finery is as follows: A charge of thin pig slabs is placed on a bed of charcoal in a shallow rectangular hearth, made of cast iron, protected from

the fire by a lining, and more charcoal thrown on, then the blast is forced through a tuyere entering on one side near the top of the hearth. The fuel is charcoal and the fusion of the metal is made to take place gradually, so that it may be fully exposed to the oxidizing effect of the blast. At the moment of fusion the foreign elements begin to be oxidized. The silicon in the pig and its adhering sand is oxidized to silica, the carbon to carbonic oxide, and some of the iron to oxide of iron. The latter combining with the silica forms a liquid slag, dissolves more of the oxide, and as it is in intimate mixture with the carburized iron, reacts upon it and removes the carbon. The mass now becoming pasty, it is well broken up with the oxidizing slag, brought up in front of the tuyere to completely

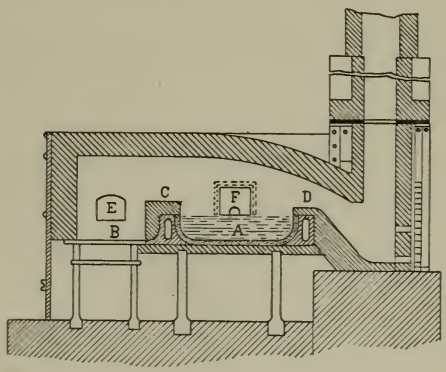


Fig. 3.

oxidize the combined carbon, and finally removed at a white heat in the shape of a spongy ball, charged with slag. In this condition it is placed under the hammer, the slag squeezed out, and the iron welded into a rectangular *bloom*.

Puddling or Pig Boiling.—This process of making malleable iron is the most important of all and the one in general use. In the operation a reverberatory furnace is employed and the reactions going on in the operation of puddling are about the same as those in the hearth finery, the decarburization of the pig iron being effected by the joint action of the air current produced by a chimney instead of the blast from a tuyere, and by oxidizing fluxes, hematite, magnetic oxide, forge scale, or the molten slag. By the employment

of the reverberatory furnace, the metal only comes in contact with the gaseous products of the fuel combustion, and is less exposed to deleterious elements in the fuel. This process is divided into *puddling* or *pig boiling* and *dry puddling,* in the former the puddler relying mainly upon the air for the reduction, while in the latter method the work is largely done by the oxides used in *fettling* the furnace lining and bed.

The form of the reverberatory furnace is illustrated in Fig. 3. The sides of the hearth *A* are made of hollow cast-iron plates kept cool by water circulating through them, backed with fire-brick and protected by a material rich in oxide of iron, such as broken slag, hammer scale, and red oxide of iron. The bottom is a flat cast-iron plate supported by columns and covered with "fettling" as above. *B* is the furnace, the grate area is from one-third to one-half that of the hearth, and the fuel used is a free-burning, long-flame coal, generally bituminous. Between the grate and the hearth is the fire-bridge wall *C,* preventing any fuel from passing over on the hearth, or any molten metal falling over on the fuel. Similarly another bridge *D,* called the flue-bridge, is situated at the further end, or flue end, of the hearth, and prevents overflow of the metal at that point. The working-door *F* is on the same side as the fire-door *E,* opposite the middle of the hearth, and is used only to introduce and withdraw the charge. A small rectangular notch, called the *stopper hole,* is cut out of the door for the entrance of the tool used in stirring or *rabbling* the metal bath. A damper is fitted to the chimney to regulate the draft.

The process may be generally stated to include the following operations:

1st. The melting down of the charge.

2d. Working the oxidizing flame with the furnace contents at a low heat.

3d. Elimination of the carbon by stirring at a high furnace heat.

4th. The balling stage or rolling up the pasty iron into balls for hammering.

In the above operations the charge, consisting of about 500 pounds of pig metal, is broken up and laid on the furnace bed, together with the necessary amount of ore, or cinder and hammer scale. The damper is opened wide, and in about half an hour the

metal is fused to a molten pasty mass in the hearth, much of the silicon and phosphorus having been removed by oxidation. The damper is now lowered to give more time for the chemical reactions, and the puddler now stirs the fluid mass with his rabble, thoroughly mixing the metal with the oxides added, produces a rapid boiling and frothing, due to the escape of carbonic oxide, and the temperature rises. The furnace lining also contributes to the oxidization by the reduction of the oxides of which it is composed. During this period the puddler facilitates the action by constant stirring or rabbling and reaches every portion of the bed. The remaining silicon and more carbon have been oxidized during this stage, reducing the latter to less than one percent.

As the carbon diminishes, the ebullition ceases and small spongy masses of malleable iron commence to appear in the bath of molten slag. The metal is raised and broken up from time to time, and the damper raised to thoroughly liquefy the slag, in order to facilitate its separation from the iron. During this period the remainder of the carbon and manganese are removed together with phosphorus.

The last operation consists in forming up the balls, which is done by detaching the pasty spongy masses of malleable iron, now at a full welding heat, and with the tool rolling them over the bed into balls of about 80 pounds. These are collected in front of the fire-bridge end, and after the whole charge has been balled up a final heat is given, the balls removed separately, taken to the hammer or squeezer and *shingled,* that is, the malleable iron particles welded together and the slag squeezed out. From 6 to 8 heats can be made in twelve hours.

The chemical changes occur in the following order as noted above. The silica formed is fluxed off by the oxide of iron, and the carbon which replaces FeO in the slag, making it very liquid, while the is removed as carbonic oxide. Manganese is oxidized to MnO, phosphorus is removed by oxidation and passes into the slag as phosphate of iron.

Dry Puddling.—This was the original process of puddling, although pig boiling is the one most universally employed. For dry puddling the iron must be white or refined iron, as in heating the metal never becomes fluid, but pasty. In this condition it is well stirred and rabbled, so as to bring all parts under the oxidiz-

ing influence of the air passing through the furnace. As the carbon, silicon, etc., are oxidized the iron becomes less fusible, the temperature is then raised and the particles of iron collected in balls as in the wet process. In pig boiling, or the wet process, it is shown that the decarburization of the metal is effected practically, entirely by the oxide of iron from the fettling, and the scale in the charge, while in the dry method it is mainly effected by the air. In the dry method there is a less waste of metal and a smaller consumption of fuel.

Sulphur is not removed by oxidation in these processes above mentioned, but a considerable quantity goes into the slag by liquation.

Many mechanical contrivances have been used to supersede the method of working the rabble by hand, but are little practiced.

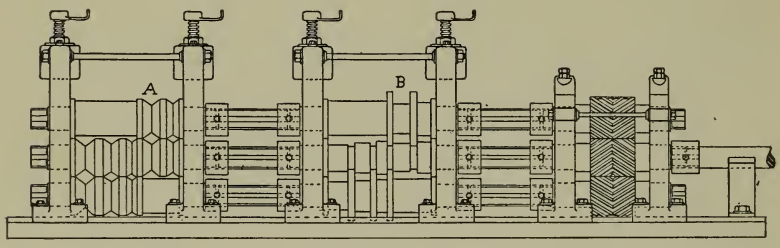


FIG. 4.

Mechanical furnaces are also in use whereby the balling is effected by revolving or rotating the furnace. Of these may be mentioned Danks, and the furnaces of Pernot.

Puddling furnaces are also heated by gas and provided with regenerators.

The puddle ball as taken from the furnace is a spongy mass of iron in which the pores and cavities are filled with cinder, and the object of the succeeding processes is to reduce the mass to a form of strong, homogeneous plate or bar. This is done by successive smelting and working after each heat, and running through the mill. The details are not permissible in an elementary book of this character but can be briefly stated in the following:

After shingling and squeezing and the ball converted into a rectangular bloom, with the slag thoroughly expelled, it is taken

to the *rolls* or *forge train,* consisting of the *roughing* or *cogging rolls* with V grooves, *A,* Fig. 4, and then to the *finishing rolls B,* a series of rectangular grooves. The bars and slabs of iron obtained by shingling and rolling are now cut up into bars of short lengths, arranged in fagots, reheated, hammered, and rolled to the desired shape. Repetition of the process improves the quality and increases the uniformity. After one re-working the iron is called *merchant bar,* after the second, *best or refined bar,* while after the first or preliminary roll it is called *muck bar.*

The product of the rolling mill is either bar iron, plate or sheet iron, beams and girders of any peculiar shape for special kinds of construction.

Tin-plate is thin sheet iron coated on both sides with a thin layer of tin. The thin plates from the rolls are cut and cleaned in warm dilute sulphuric acid, in a leaden vessel, then washed and scrubbed with sand and immersed in a bath of melted tallow. They are then immersed in the *tin pot* and submerged in molten tin, the surface of which is covered with grease and kept clean by plunging into it wooden sticks. This tinning is repeated in another pot called the *wash pot,* and containing tin of a better quality and lower temperature. From this the plates are taken to the *grease pot,* in which under grease a small quantity of tin is kept at a temperature exceeding the melting point, and the superfluous metal strained off. After this the edge of each plate is dipped into the *list pot* containing melted tin about one-fourth of an inch deep, in order to remove the bead formed at the lower edge of the plate; when striking the plate sharply the superfluous metal is removed. The plates are then scoured with bran and woolen cloths, and are ready for inspection and classification.

Galvanizing.—Galvanized iron is the term applied to sheet iron, and iron articles coated with zinc to resist corrosion. Formerly the zinc was applied by means of the electric current and known as the *wet* or *electrolytic method.* This method was found to be costly and slow, and the results obtained were irregular and unsatisfactory. In consequence it has given place to what is known as the *dry* or *molten-bath* process. This latter method is more difficult of management for bulky objects, owing to the large bath required of molten material, the deterioration of this bath, and other

mechanical difficulties, hence the process is limited to articles of comparatively small dimensions.

The dry or molten method consists in dipping the clean iron into a bath of molten zinc, the surface of which is covered with sal ammoniac in order to prevent oxidation, and at the same time to remove any oxide that may be formed. The iron is first cleaned in dilute sulphuric acid before dipping it into the molten zinc.

Russian sheet iron is a thin sheet iron with a smooth polished surface and not likely to oxidize readily, the bright surface is iron oxide. The sheets are made of a fine quality of wrought iron rolled and annealed. The smooth polished surface is given by hammering packages of the sheets with charcoal interposed.

CHAPTER II.

STEEL AND ITS MANUFACTURE—NON-FERROUS METALS AND ALLOYS.

Steel.—Before the introduction of the modern processes of steel-making the term steel could be clearly defined, and was known practically as a combination of iron with sufficient carbon, so that it could be hardened by sudden quenching from a red heat, and again softened by heating and cooling slowly. With the introduction of the Bessemer and the Siemens' processes, this definition does not hold, since a metal is produced of the character of steel, but with little carbon in its composition. It does not possess the hardening property common to high-carbon steel, nor has it the fibrous character of malleable iron. To distinguish this metal from high-carbon steel, or tool steel, the term *mild steel* was devised to characterize those steels containing less than 0.5 percent of carbon. Steel proper contains from 0.5 to 1.5 per cent of carbon.

Properties of Steel.—The higher the carbon the finer is the fracture of steel, the color of the fracture being a bright bluish-grey, crystalline, and approaching white in the hardened varieties. It is malleable, but requires to be worked at a lower heat than wrought iron, else burning will result; the tenacity varies from 45,000 to 95,000 pounds per square inch, and depends upon the carbon present. High-carbon steel may be hardened, annealed, and tempered. The welding property is possessed by steel in proportion to the carbon it contains, this property decreasing with the increase in carbon. For a flux in welding steel, sand, and a mixture of borax and sal ammoniac are employed.

Steel may be made by the *direct process* from iron ore after the manner previously explained for wrought iron, and then carburizing to the required extent. For our purpose we will consider only the four general methods of steel manufacture under the indirect method: (1) The *cementation process;* (2) *crucible cast steel;* (3) *Bessemer process;* (4) *open-hearth steel.*

The Cementation Process.—This method of manufacture is based upon the fact that when iron is heated with carbon to a high temperature and not in contact with the air, carbon will be absorbed by the iron, converting it into steel.

The furnace employed is represented in Fig. 5, and consists of a rectangular structure of brickwork divided into two parts by a narrow fireplace *A*, with a door at each end for the fuel supply. On each side of the fireplace is a converting pot or chest *BB*, made of fire-brick and so arranged on bricks or pedestals as to permit the heat to circulate around them before escaping to the chimney. An arched roof is built over the pots and the fireplace, and the heat

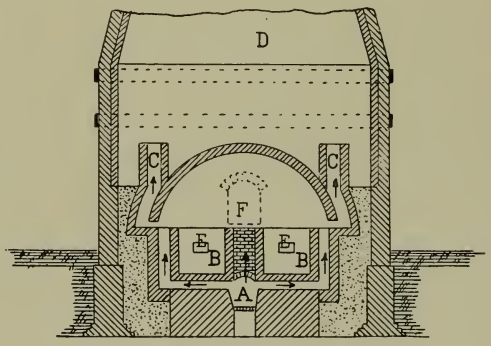


FIG. 5.

and flames, after enveloping the pots and filling the arch, pass out on either side through the flues *CC*, to the chimney *D*.

The chests are charged by first covering the bottom with a layer of charcoal and then bars of iron are packed in layers, each bar surrounded by charcoal until the pot is filled, when they are topped with charcoal. The whole is then covered with dry sand or clay. After sealing up the manhole *F* by which entrance is gained to the chests, the furnace is slowly heated up, attaining the maximum temperature in about two days, which is steadily maintained for several days longer, depending upon the amount of carburization desired. Trial bars are placed where they may be withdrawn for examination during the operation. These openings *EE* are plugged with clay. After the carburization has been found sufficient,

the fires are allowed to die out and the furnace gradually cooled down. This occupies a week or more and the steel is then removed and sorted. The bars are found covered with small blisters, from which the material derives its name, *blister steel,* highly crystalline and brittle.

When the blister steel is cut into lengths, fagoted, heated, and welded under the hammer or rolled, it becomes more uniform and is known as *shear-steel* or *single-shear.* By giving a second reheating with piling and welding, the metal is known as *double-shear steel.*

Harveyized Armor Plate.—An application of the principle of cementation is seen in the Harvey process of giving extreme surface hardness to armor plates in the construction of naval vessels, to resist projectiles. The plates are originally of mild steel, and the after-process is carried on so as to produce a face of very hard steel, becoming softer from the face to the back of the plate, which is unchanged. The process is as follows: The mild steel plate, weighing from 30 to 40 tons and containing from 0.10 to 0.35 per cent of carbon, is placed upon powdered dry sand or clay on the fire-brick bed of a heating furnace. The face of the plate is covered with about eight inches of charcoal dust, and on this is placed another plate, face downwards, so that the two plates are carburized at the same time. Around the rest of the plate is placed a covering of sand, and upon this a covering of fire-bricks, the furnace openings are now closed, the edges luted with sand and fire-clay, and the furnace gradually brought up to an intense heat, remaining at that temperature for 8 or 10 days, according to the required depth of the hardening. The depth of the penetration of the carbon is dependent upon the temperature of the furnace, the time, and on the firm compression of the charcoal or carbonaceous matter against the plate. After sufficient penetration has been accomplished the plates are taken out, and after cooling to a cherry red, they are hardened by cooling with spray jets of cold water directed on the plates, and finally cooled in oil. In armor-plate mills the plates are usually prepared on special cars made for the purpose and then run into the furnace. The plates are hardened for a depth of $1\frac{1}{4}$ to 3 inches and can not be drilled or machined unless softened at the parts desired, by heating with the electric current

and the heating let down gradually. Modern furnaces are gas-fired and the heat better controlled.

Another example of the cementation process is in the operation of *case-hardening* to be described later.

Crucible Steel.—Blister steel contains small pits and seams of slag originally contained in the malleable iron, and these defects were of considerable importance in the manufacture of edged tools. To avoid this difficulty, blister-steel bars are broken up in small pieces and re-melted in crucibles, freed from the impurities, cast into ingots, and rolled to the desired shape. When large masses of steel are required, a great number of crucibles are prepared and the crucibles poured into the foundry ladle. The resulting material is uniform in character, homogeneous, and commonly desig-

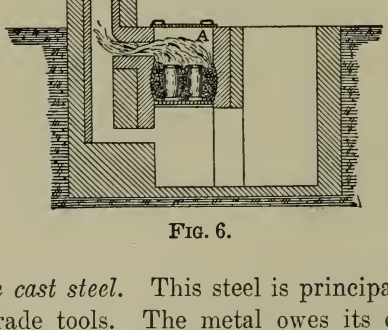


FIG. 6.

nated as *crucible cast steel.* This steel is principally used for cutlery and high-grade tools. The metal owes its excellence to the selection of good raw material, the care in assorting it, and the uniformity of the texture acquired by fusion.

The furnace, Fig. 6, is usually a fire-brick compartment with rectangular chambers holding two crucibles each. The chambers *A* have a common flue *B* and the tops level with the floor. The blister steel, after having been broken up, is introduced in the crucibles, the lids put on, and the furnace closed and started. The fuel is coke, and after four or five hours the crucibles are lifted from the fire and poured. The Siemens' gas-fired crucible furnace with regenerators is much employed for large work.

Many modifications have been introduced in the process, a cheaper process, but with not so reliable a product, is to place a

quantity of charcoal in the crucible with bar iron. When the iron is raised to the melting heat, a small quantity of *spiegel-eisen* is added.

In the previous processes mentioned, the stock used is malleable iron and the material is carburized; we will now take up briefly the processes of making the steel directly from the pig iron. This is performed by the removal from the pig of the silicon, sulphur, phosphorus, and reducing the carbon to the amount required, or to de-carburize it completely, and re-carburize by the addition of a definite quantity of *spiegel-eisen.*

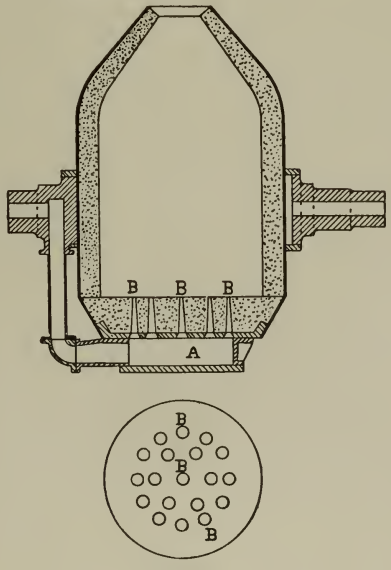


Fig. 7.

Bessemer Process.—This method consists of blowing air through molten pig iron contained in a vessel or converter until the silicon, carbon, etc., are burnt out or oxidized. As previously shown, all the impurities except sulphur are practically oxidized before the iron, so that the process can be stopped at the proper time, and then the ferro-manganese or spiegel-eisen added to give the proportion of carbon for the steel desired. This oxidization produces a high temperature, thus keeping the mass of metal in a liquid state without the aid of the ordinary fuel. The combustion of the carbon and silicon produce a temperature sufficient to keep the mass

thoroughly melted, so that the steel may be poured into moulds, making ingots of any required size.

The converter consists of a pear-shaped vessel, Fig. 7, lined with a refractory material, usually ganister, and carried on ring-fitted trunnion journals, which rest on pedestal bearings. One trunnion is connected to a hydraulic rack and pinion, in order that the converter may be turned down or tilted when necessary. The other trunnion is hollow and connected by a pipe to the blast-box *A*, at the bottom of the converter.

This box is detachable, and fitted on the upper side with a number of tuyeres *BB*, containing holes about $\frac{3}{8}$ inch in diameter, which traverse the lining mass. These tuyeres are slightly conical, about 22 inches long, made of fire-clay, and through which the blast of about 20 to 25 pounds per square inch passes through the metal. The bottom requires frequent replacement on account of the mechanical wear and chemical action, and duplicate bottoms are kept on hand, so that the removal and replacement do not cause much delay. The sides require less frequent re-lining and causes greater delay and stoppage of work.

Operation.—The pig iron to be used may be taken direct from the blast furnace or the pig may be melted in cupolas, the converter first having been gradually brought to a white heat, with a coke or charcoal fire within it. It is then turned on its trunnions to a horizontal position so that the tuyeres will not be filled with molten metal while the charge is run in. The blast is then turned on and the converter brought up into the vertical position, and the blast, a number of fine jets, passing through the entire mass of metal, takes hold of all the oxidizable elements present and burns them out. In the first stage of the process the silicon is rapidly oxidized to silica, which combining with the oxides of iron present forms a glassy slag, covering the surface and retaining the heat in the iron; the flame from the mouth being a short yellowish-red, accompanied by sparks. The second stage of the process is known as the *boil*, the carbon being burnt out to carbonic oxide which escapes, the accompaniment being a white hot flame with showers of slag. The blast is gradually reduced and the *fining* stage is reached, in which the remainder of the carbon and manganese is removed, and the flame drops and becomes nearly transparent. In

about twenty minutes from the commencement of the blow, the flame suddenly drops and indicates the almost complete removal of the carbon, and a further continuance of the blast means a great loss from the oxidization of the iron. The converter is now turned, the blast shut off, and the proper amount of spiegel-eisen added, which re-carburizes the iron, while the manganese removes the heavily charged oxygen and restores the lost malleability. After standing a few minutes to settle, the converter is turned down and the steel poured into a ladle, and carried to the moulds. The converter is then turned down vertically and the slag run out. As noted, the entire operation is governed by the appearance of the flame issuing from the mouth, and the action to be taken with the converter and with the blast is regulated accordingly by the workman in charge. Phosphorus is not removed to any appreciable extent and sulphur is not much affected, hence a good quality of pig iron, free from phosphorus and sulphur, and containing from 2 to 2½ percent of silicon, should be employed. The metal usually employed is known as *Bessemer pig,* and is smelted from ores similar to red hematite and magnetite.

The ladle is made of malleable plate iron and lined with material similar to that in the converter. The *teeming* or pouring from the ladle is effected through a tap hole at the bottom; by this means the slag in the ladle is prevented from going into the mould. The tap hole is opened and closed by a fire-clay stopper, manipulated by an iron rod, protected with a fire-clay tube, and projecting over the top edge of the ladle.

The above process is known as the *acid process,* owing to the siliceous nature of the lining of the converter, while the slag is a basic silicate of iron and manganese. Only two elements are burned, viz., carbon and silicon, the silicon furnishing most of the heat, while under the conditions phosphorus is untouched and can not be treated. By lining the converter with a basic material instead of an acid material, the slag produced is also basic and will take up elements whose oxides are acid, hence, phosphorus can be readily removed from iron under the conditions.

The Basic Bessemer Process.—The converter is similar to that in the acid process, but the lining is made of a basic material, usually burned dolomite. With a basic lining the percentage of

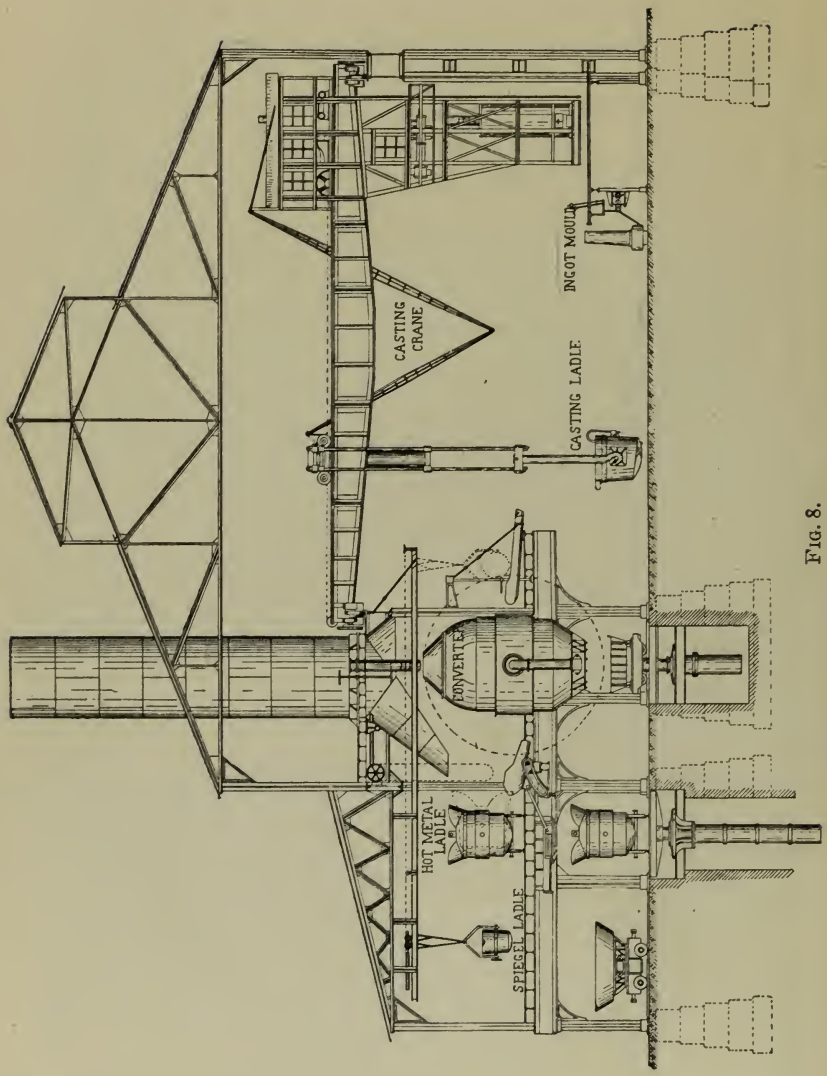

CASTING CRANE
INGOT MOULD
CASTING LADLE
CONVERTER
HOT METAL LADLE
SPIEGEL LADLE

FIG. 8.

silicon is kept low, as the silica formed in oxidation attacks the lime lining, and under these conditions another source of heat is necessary. This is found in phosphorus which must be present in considerable quantity, the iron containing as high as 3 percent. Hence the Bessemer process can be used for two kinds of ores—those furnishing iron with but a trace of phosphorus (acid process), and those containing it to a high percentage (basic process).

Operation.—Before placing the charge in the converter a quantity of lime is introduced with coke and blown. The charge is then run in and the process is the same as before, except with the removal of some of the phosphorus, up to the time when the flame drops. Instead of shutting off the blast, it is continued, the remainder of the phosphorus is oxidized, combines with the lime, and passes into the slag. Samples of the metal are taken, and by testing the fracture and the malleability, the point at which the phosphorus is eliminated and the blow stopped, is ascertained.

The final operation of adding spiegel-eisen or ferro-manganese is practically the same as in the acid process, the charge is then poured into the ladle and transferred to the moulds.

Owing to the method of manufacture, the rapidity with which it can be made, the quantity, and the machinery method of its production, Bessemer steel can be produced very much cheaper than the other grades of steel.

In Fig. 8 is given an illustration of the arrangement of the Bessemer system of a modern American steel plant, in which the location of the converter, ladles, cranes, ingot moulds, etc., are all marked and the details of a working plant clearly indicated.

The Tropenas Process of Steel-making.—This converter steel process has, within recent years, been brought into considerable prominence, from the facility which, at comparatively small expense, the process may be employed in the ordinary iron foundry, and is now extensively used.

The Tropenas plant consists of a special converter in which iron, melted in a cupola beforehand, is converted into steel. This vessel, like all other converters, is a sheet-steel shell lined with silica bricks or ganister. The shell is fitted with two hollow trunnions, carried on pedestals, so that the apparatus may be tilted according to the

requirements of the operation, i. e., charging the molten iron, pouring the steel, etc. The interior of the converter is so designed that the metallic bath has a much greater depth than in any of the other pneumatic processes. The blast enters the converters from the pressure-blower through the trunnions, feeding the wind boxes and tuyeres, of which there are two independent sets, one above the other, both above the surface of the metallic bath, and each fitted with separate pipes and valves regulating the pressure and volume of air.

Before commencing operations the converter is heated by means of coke or crude oil; afterwards no fuel is needed in the converter, as it is supplied by the metalloids in the iron which are to be eliminated. The pig iron and steel scrap having been melted in the cupola or other furnace is run into the converter, and the position of the converter relative to the level of the metal is then adjusted to the proper condition for blowing. The blast is started, and at a certain period of the operation a supplementary blast is introduced at will by means of the auxiliary tuyeres. This completes the combustion of the escaping gases, raising the temperature of the bath by radiation. At the end of the operation a bath of very fluid and soft metal is the result, and re-carburization is made in the vessel or in the ladle as in other steel processes. By varying the final additions, steel of any desired hardness or quality may be produced exactly. The blast-pressure required varies between three and four pounds per square inch, according to the kind of pig iron treated.

The characteristic features of the Tropenas process are the following:

First. Low pressure of blast, always above the surface of the metal.

Second. Special disposition of the tuyeres in the horizontal plane, so that the jets of air will enter into the converter above the bath, and will not impart to it any gyratory or tumultuous motion whatever.

Third. Great depths of metallic bath, so as to avoid churning and stirring during the operation. The result is that the steel contains very little occluded gas and, therefore, pours quietly into the moulds, producing castings free from blow-holes.

Fourth. Arrangement of auxiliary or "combustion tuyeres," so as to burn the combustible gases which escape from the bath and which in all other pneumatic processes pass unconsumed up the chimney. This combustion greatly increases the temperature and makes the subsequent manipulation of the steel in the pouring, etc., much easier and more satisfactory. In making large castings it is often necessary to add cold scrap to the steel in the ladle, or to let it stand exposed to the air some minutes to cool before pouring.

The Tropenas process has this advantage, that, being so very hot at first, a great number of the lightest castings are taken care of. Using always lip-pouring ladles for large and small castings alike, one is able to judge from the surface of the metal its suitability as to temperature for any purpose.

Though the metallic bath is practically quiet during the operations, the reactions caused by the fining or combustion blast are quite sufficient to secure a perfect homogeneity of the charge.

The loss of metal during the operation, including cupola and converter, is about 17 percent, which is not large considering that the loss in cupolas alone varies from 5 to 7 percent, and that the iron treated usually contains from 5 to 7 percent silicon, carbon, and manganese to be eliminated.

The lower the sulphur and phosphorus the better the results.

The sands required for making moulds are the same as used in other steel foundries and the moulds are dried or not, according to the kind of castings to be made. Many small and medium castings are made in green sand moulds. The steel as it comes from the sand is perfectly soft and malleable and the great majority of the castings delivered to the machinery trade are neither re-heated nor annealed.

Each converter works usually in connection with a cupola. The cupola is operated in the usual manner, the depth below the tuyeres is greater than in the ordinary cupola, so as to hold more metal in the well. The final additions for the converter are melted in a crucible furnace or a small cupola. Each operation in the converter lasts from 12 to 20 minutes. The time required for pouring the steel into the ladles and preparing the converter for another blow, varies according to the style of castings made. Whenever small

castings are manufactured and the whole charge has to be poured into hand ladles, 40 minutes are required for a complete operation.

Open-hearth Process.—This is a process for the production of steel on the hearth of a regenerative gas furnace. There are two methods in general use, the *pig and ore,* or *Siemens' process,* and the *Siemens'-Martin,* or *pig iron and scrap process,* steel scrap and ore being used. The process may be acid or basic according to the character of the bed or hearth, silica sand (acid), or dolomite, or magnesite (basic). As in the Bessemer process, the components

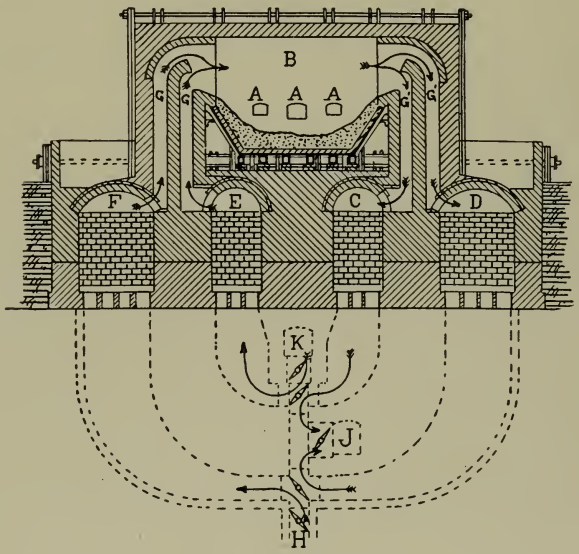


FIG. 9.

of the charge for the acid process must be free from phosphorus and sulphur.

Siemens' Regenerative Furnace.—The furnace is a double-ended reverberatory gas-fired furnace, shown in Fig 9 in longitudinal section, while the dotted lines show a diagram in plan of the flues. *AAA* are the furnace doors, the middle one for working the metal, the others for charging, *B* is the furnace chamber communicating at each end with a pair of chambers *CD, EF,* by means of the flues *GG'*. The chambers are built of chequer brickwork with zig-

zag passages, which are alternately heated by the hot gases from the furnace on their way to the chimney. When the reversal valves are shifted this absorbed heat is given up to the cold air and fuel gas passing upward on their way to the furnace through the flues *G'G'*. The chambers are worked in pairs, *CD* and *EF*, the outer ones for the passage of the air are larger, while the inner ones are for the gas. One pair of air and gas chambers is always being heated up, while the air and fuel gas are passing through the other. The valves are shifted and the direction of the air and gas reversed every half hour. The air flue is shown at *H*, the chimney flue at *J*, and the gas flue at *K*, together with their appropriate valves.

The Siemens' Process.—This method of the open-hearth manufacture is similar to wet puddling, and is worked with pig iron, and pure rich oxides added to the molten metal in the furnace. The pig iron, varying from 8 to 40 tons, is melted on the furnace bed, and the oxide, in the shape of red hematite or any other pure oxidized ore, is added in small portions at intervals, which effects oxidation and removes the silicon, manganese, and carbon. The metal is then recarburized by the addition of spiegel-eisen or ferro-manganese. The time occupied varies from 10 to 14 hours, and samples are taken at various stages of the operation, and by a rapid analysis the character and the carbon value determined and modified.

Siemens'-Martin Process.—In this method the decarburization of the pig iron is effected by melting a large amount of scrap wrought iron and steel. After melting, the bath is fed with iron ore a little at a time, and the oxygen of the ore oxidizes the carbon. The progress of the oxidization towards the end of the boil is ascertained as before, by removing a small sample in a ladle from time to time and testing. Sufficient carbon is restored by the addition of spiegel or ferro-manganese, as required, before tapping.

As in the Bessemer process, if sand is used for the furnace bed the pig must be Bessemer pig iron, but with the basic process iron containing phosphorus can be used and lime charged in the furnace. Also in the basic Bessemer process it has been stated that phosphorus is needed to assist in the heat production; in the basic open hearth this is not the case, and it should be as low as possible.

Fig. 10 gives a graphic representation of the various processes just described, through which iron ore passes from its initial smelting operations, through the succeeding steps for wrought or malleable iron, and the different steel-making methods, until the product is ready for the shop or the market.

Segregation.—After pouring the steel, the liquid ingot while cooling goes through a process called *segregation,* in which the carbon phosphorus and sulphur becomes squeezed out or concentrated in the central part, and then rise to the upper portion. This

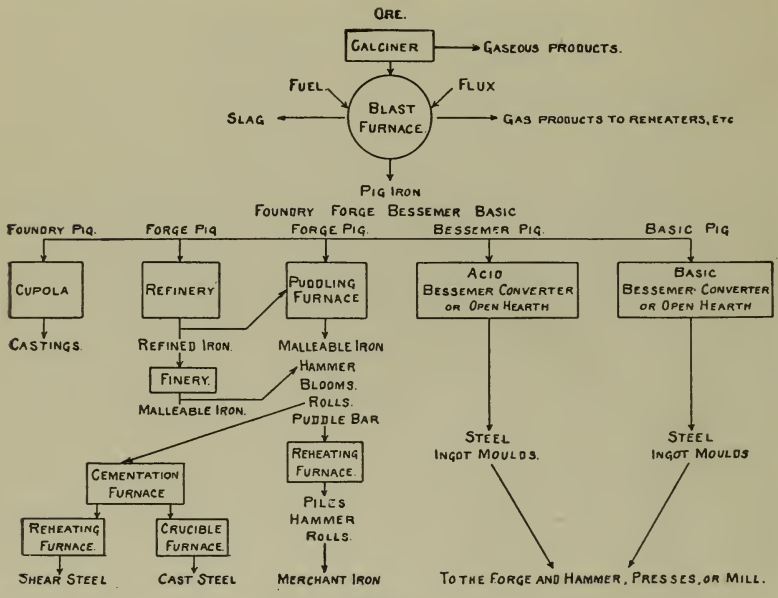


FIG. 10.

defect is eliminated by cutting out and rejecting the upper part of the ingot, which is usually made about 25 percent in excess.

Honey Combing.—In the ingot mould the disengagement of the dissolved gases, mainly *H, N* and *CO,* during cooling, form minute bubbles, and unless counteracted produce a vesicular condition in the mass termed *honey combing.*

Cavities settle in the mould, due to the shrinkage in solidification, and form cavities or pipes, generally in the upper part, which is broken off before working.

Special Steels.

Manganese Steel.—This is an alloy containing from 11 to 14 percent of manganese and very tough and hard, its tensile strength reaching from 60 to 70 tons per square inch, with an elongation of 35 to 40 percent in 8 inches. It can not be welded and is so hard when cold that it is difficult to work with ordinary tools.

Chrome steel is a steel containing a small amount of chromium. It is hard, brittle, and has a limited use.

Tungsten Steel.—By alloying with tungsten, the steel is greatly increased in hardness, without excessive brittleness in the cold metal, or difficulty in working when hot. The addition of from 5 to 9 percent of tungsten with manganese forms what is known as *self-hardening* or *air-hardening* steels, of which Mushet's steel is an example. These steels derive their name from the fact that when heated to an orange color and allowed to cool slowly in the air, they become exceedingly hard. The hardness of Mushet's steel can not be increased by the ordinary methods usually employed in hardening. It must be hammered to its final shape at a red heat, leaving grinding as the only operation to be performed in finishing. Tools made of this steel remain hard at a comparatively high temperature and can be used for cutting metal at a much higher speed than with carbon steel, as the heat caused by the friction of high speed would soon soften and render useless the best carbon steel. This material is being rapidly overshadowed by a later steel known as *high-speed steel,* whose surprising qualities are described under *Lathes and Lathe Tools.*

Nickel Steel.—This alloy of steel and nickel, containing from 2 to 4 percent of nickel, and from 0.2 to 0.3 percent of carbon, is largely used in naval machinery and hull construction, on account of its much greater strength and toughness than carbon steel. Its power of resisting shock and its toughness makes it especially valuable in the manufacture of armor-plate, and parts of machinery subjected to heavy blows or shock. For the best results the material should be oil-tempered. The U. S. Navy machinery specifications (see Appendix) require for this steel a minimum tensile strength, Class A, of 95,000 pounds per square inch.

Non-Ferrous Metals and Alloys.

Copper.—This metal has a deep red color and is used to form alloys more frequently than used by itself, as it is too soft and weak alone for general purposes. It possesses the properties of malleability and ductility to a marked degree, and its use is greatly extended by the addition of small quantities of other metals, forming alloys.

Copper is principally employed in the shape of sheets, bars, and wire. It is employed for steam pipes and water pipes, for the manufacture of chemical vessels, and from its high conductivity for electricity, it is an important item in electrical work. Large steam pipes are made from sheets curved to shape by hammering or rolling and then brazed at the seams. Smaller pipes are solid drawn, and in general use in the navy for much of the piping, such as feed and blow pipes and the smaller and complex shapes of steam piping. The tensile strength is about 30,000 pounds.

Tin.—This metal is seldom used alone and is one of the principal constituents of the brasses and bronzes. Its tensile strength is exceedingly low, but it has considerable ductility and greater malleability. Its principal use is in the manufacture of alloys with copper, zinc, lead, etc., rolling into very thin sheets called *tinfoil,* in tinning different materials as a protective covering from the corrosive action of salts and acids, and in the manufacture of tinplate.

Zinc.—This metal is seldom used alone but largely employed to alloy with copper. In its simple state it is used as zinc slabs to counteract corrosion in boilers, hot wells, condensers, and evaporators, by placing the zinc in direct contact with the metal requiring protection. Zinc is extensively employed in the form of sheets for roofing purposes, sheathing, etc., from the fact that it is impervious to the effects of the weather. The industry known as *galvanizing,* that is, iron with a coating of zinc upon it to prevent it from oxidizing, is in reality no galvanic action, but a purely chemical process due to the formation of a zinc-iron alloy on the surface of the iron, the material then being called *galvanized iron.* The tensile strength of zinc is even lower than tin.

Lead is inelastic, soft, with but little tenacity, but with great malleability. It is extensively used in the form of sheet lead and

lead pipe. It is very heavy, easily fused, and but little liable to oxidization in the open air. Lead oxides are of great value, red lead is used as a pigment when mixed with drying oils, and in engineering, when mixed with white lead, as a cement or materials for joints.

Antimony is useful in alloys on account of the powerful effect it has in hardening other metals and alloys. It is very brittle, highly crystalline, and of a silvery appearance.

Alloys.—The physical properties of an alloy are often different from those of the constituent metals; as a rule the tenacity, hardness, and fusibility are greater than the mean of the constituents; the color is not always dependent upon that of the ingredients, and it is not a matter of indifference in what order the metals are melted in making an alloy. Generally the alloying of one metal with another lowers the melting-point, and sometimes reduces it below that of the most fusible component.

The Brasses.—This term is applied to alloys of copper and zinc, brass as usually designated being a proportion of $66\frac{2}{3}$ copper, and $33\frac{1}{3}$ zinc. Care must be taken in fusion that the loss of the zinc by volatilization is the least possible, as its melting-point is considerably less than copper, and is added just before pouring.

These alloys are strong and many of them are malleable, among them may be mentioned, Muntz metal, common brass, brazing spelter, tube metal, etc., the varied composition of which can be seen in the Appendix.

Muntz metal is a brass composed of 60 percent of copper and 40 percent of ~~tin~~ zinc. It has high tensile strength and largely used in naval and marine work in general for bolts, pins, rods, etc., on account of its tenacity and the forging qualities it possesses.

The Bronzes.—The copper-tin alloys are generally known as bronzes and consist of gun-metal, bell-metal, and speculum alloys. Bronzes for bearings and pieces subject to severe friction are made in many proportions.

Phosphor bronze is a bronze containing a small proportion of phosphorus introduced either in the form of phosphor tin or phosphor copper. This metal is hard and tenacious and much used for valves, bushes, gear wheels, etc. Tensile strength from 17 to 22 tons per square inch.

Manganese bronze is a bronze to which is added ferro-manganese. This makes a valuable metal in marine work as the metal can be rolled, drawn, and forged and has a high tensile strength. The material is used for general engineering work, and in naval engineering is exclusively used for screw propellers. Tensile strength from 20 to 25 tons per square inch.

Aluminum Bronze.—The proportion of aluminum is from 1 to 10 percent. The alloys are as strong as mild steel, malleable, elastic and ductile.

Copper-Zinc-Iron Alloys.—These alloys show a remarkable increase in tenacity due to the contents of iron. One of the principal examples of these alloys is *Delta-Metal,* formerly known as *Sterro-Metal,* with a percentage composition of 60 copper, from 34 to 44 zinc, 2 to 4 iron, and 1 to 2 tin. In the manufacture of Delta metal the wrought iron is first dissolved in molten zinc, the latter readily dissolving or absorbing the former to about 5 percent and the iron can thus be introduced in any definite amount into the copper alloy up to 5 percent. The characteristics of this alloy are great strength and toughness, can be rolled and forged hot, and within limits will stand drawing and hammering when cold. Produces a close-grain casting and tarnishes less than brass.

Tobin Bronze.—Another example of copper-zinc-iron alloys is *Tobin bronze,* and is practically a Delta metal with a small addition of lead making the material softer, the composition of tobin bronze as given by Dr. Dudley is:

Copper	59.00	percent.
Zinc	38.40	" "
Tin	2.16	" "
Iron	0.11	" "
Lead	0.31	" "

The tensile strength of the rolled bronze is 79,000 pounds with an elastic limit 54,000 pounds. At a cherry red the material can be forged and stamped and is much used for bolts and nuts in machinery specifications for U. S. Navy. From its high tensile strength and resistance to the corrosive action of sea water, Tobin bronze has a large field in marine work for steam launch shafting, ship sheathing, fastenings, hull plates for yachts, etc.

Bearing Metals.—These alloys are used for lining bearings as the friction is reduced, does not heat readily, can be readily removed, and renewed, and in general gives better results with rapid-moving machinery. The bearing metal is run into cavities of various forms in the bearings, details of which are explained later in the Engineering Course. The principal constituents of bearing metal alloys are copper, tin, zinc, lead, antimony, iron, and aluminum.

Babbitt Metal.—This is one of the oldest and best known of bearing metals, and consequently there are many compositions sold in the markets under this name, some worthless, others good. The proportions vary according to the different manufactures, the original composition is claimed to be:

Tin	89.3 percent.
Copper	3.6 " "
Antimony	7.1 " "

The manufacture is as follows: The copper is first melted and the antimony added first, then a portion of tin with the whole at a dull red heat, and constantly stirred until the parts were well mixed. After this the balance of the tin is added and after a thorough stirring the alloy is cast into ingots.

The Bureau of Steam Engineering, Navy Department formulæ, and used where babbitt metal is specified at the different navy yards, consists of:

Banca tin	88.8 percent.
Best refined copper	3.7 " "
Reyulus of antimony	7.5 " "

Other bearing metals in common use, and known under the general term of *white-metal alloys*, are Magnolia, Parson's, Richards', Fenton, and others. For the composition of these alloys and of the various brasses, bronzes, solders, etc., the student is referred to the Appendix.

The Manufacture of Lead Pipe.*—By the aid of hydraulic machinery lead pipes are produced by forcing them out of the solid lead. The apparatus used is shown in Fig. 10a. The press *PQ* consists of a massive iron cylinder and a piston *BC*. This piston

* Spons' Dictionary of Engineering, Volume III.

or plunger is narrowed at the end and turned, so as to fit tightly into a very strong iron cylinder *GH*. In the bottom of this cylinder is a hole *O*, which is carefully turned to the exact external size of the pipe to be produced. At *E* is a small arch, from the top of which a mandrel descends down through the hole. This mandrel is exactly the internal diameter of the pipe. The charge of from 2 to 4 cwt. of molten lead is poured into the space *D*, and left to solidify. Round the cylinder *GH* is another cylinder *KL* of larger diameter, and between these cylinders a fire is kept up for the purpose of preserving the lead at the proper temperature. When this temperature has been reached by the cooling of the molten mass,

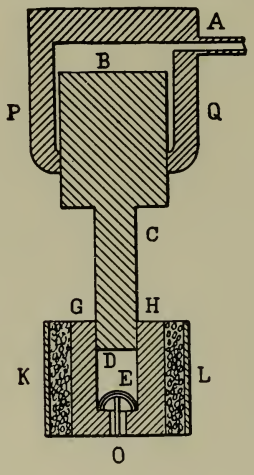


FIG. 10a.

pressure is applied to the plunger, which descends with great force. The lead is thus forced between the cylinder hole and the mandrel, like a lump of putty under ordinary pressure, and it issues at the bottom as one continuous pipe. It will be at once seen that an immense length of ordinary pipe is obtainable, without joint, by this process. In practice, however, it is usual to cut the pipe off in lengths of 60 feet for convenience of stowage and transportation. A remarkable fact in this process is that the solid lead, which is divided by the arch *E*, joins again below the arch under the influence of the hydraulic pressure without leaving any trace of the division it has undergone.

CHAPTER III.

THE PATTERN-SHOP AND PATTERN-MAKING.

Pattern-making and moulding are so closely related, and success in moulding is so largely dependent upon a properly constructed pattern, that the pattern-maker is naturally required to know at least the elementary essential principles of moulding, the various failures likely to occur from badly conceived pattern-work, and ability to read drawings correctly.

In order to make a mould of any desired form, a pattern must be made of the required shape, and also a material to receive the pattern, adhesive enough, and capable of receiving and retaining the impression of the pattern, so that when the molten metal is run into the space formed by the pattern, it is not broken up by the violence of the flowing metal, and a good representation is obtained.

Wood.—Of the different kinds of wood employed in pattern-making, pine is the most extensively used on account of its uniformity, abundance, and clean and easy working. It should be of the best quality, straight-grained and free from knots.

For fine work, or where durability and many castings are required, mahogany is frequently employed, as pine patterns are apt to wear out from the rough usage in the foundry, and are liable to warp. Mahogany shrinks but little and warps less than any other wood, but its use is limited by the expense of the material. Other kinds of wood used in pattern-making are well-seasoned cherry, maple, ash, redwood, beach, teak and boxwood, while for light objects or delicate patterns, and where expense is not an item, or where great length of service is required, metal patterns are used.

Well-seasoned wood is a requisite, especially with patterns that are to have any permanent value, as otherwise they warp, split, change form, and become a source of great loss in economical working. To season timber, it is exposed to the air in a dry situation, stacked slightly above ground with free circulation of air around it, and given ample time. When want of space or other considerations intervene, artificial seasoning is resorted to, by placing the timber

sawn into planks, in racks, in proper ovens or kilns heated by waste heat from the plant, not too high in temperature, and with a steady current of dry air through the material.

With hard and unabsorbent woods, such as ebony and boxwood, simply smoothing or polishing will enable them to be drawn from the sand without adhesion, but with softer woods the pattern, after finishing, is coated either with varnish, oil paint, or shellac, then carefully rubbed down with fine sand paper and finished with powdered chalk, until the surface is smooth and glossy. By this means any adhesion of the sand to the pattern on withdrawal is obviated, with a resulting clean sand mould.

Shrinkage.—Certain allowances must be made in the pattern, so that it differs to some slight extent from the size and shape of the drawing. There must be a slight clearance allowed for removing the pattern from the sand by which it is enveloped; the casting itself contracts or shrinks into a less compass on cooling, this shrinkage rate varying with the different qualities of the same metal, with the shape and bulk, and with different metals. To allow for this the pattern is increased by an amount determined by the "shrinkage rule" and the skill and experience of the pattern-maker. The effects of unequal shrinkage should be carefully examined before designing. Unequal cooling produces internal strains and the part cooling first will be compressed by the parts still cooling, and a thin part joining a thick part without a gradual increase in thickness, the cooling will often produce such strains as to cause a rupture at the junction. The shrinkage, sides and ends of a casting 5 or 6 inches or less in size, is compensated for by the shake in the sand or *rapping* given by the moulder to the pattern in order to extract it from the sand. In the following table is given the shrinkage in castings of various shapes and material:

Shrinkage of Castings.

Locomotive cylinders	$\frac{1}{16}$	inch in a foot.
Pipes	$\frac{1}{8}$	" " 15 inches.
Girders, beams, etc.	$\frac{1}{8}$	" " "
Large cylinders, 70″ diameter, 10′ stroke, the contraction in diameter about	$\frac{3}{8}$	" at top.

Large cylinders, 70″ diameter, 10′ stroke, the contraction in diameter about	$\frac{1}{2}$	inch	at	bottom.
Shrinkage of length	$\frac{1}{8}$	"	in 16	inches.
Thin brass	$\frac{1}{8}$	"	" 10	"
Thick brass	$\frac{1}{8}$	"	" 12	"
Zinc	$\frac{5}{16}$	"	" 12	"
Lead	$\frac{5}{16}$	"	" 12	"
Copper	$\frac{7}{32}$	"	" 12	"
Tin	$\frac{9}{32}$	"	" 12	"

Watkins on the subject of shrinkage in castings offers as a general law that the most metal in a mass always shrinks last, hence if a casting be composed of irregular thickness it will be liable to be broken by the forces contained within itself. Columns and castings, supporting or resisting great pressures, should be so designed as to prevent this great error. Mouldings on columns are often designed so that the columns are very weak where they should be strongest. A good plan is to bolt mouldings instead of casting them on a column. Many of the failures and irregularities in castings of irregular shape can be remedied by care in cooling the casting while in the mould, for instance, by removing or breaking up the sand from a particular casting it will straighten in the shrinking; also shrinkage takes place in changing from a red to a black heat.

With solid globular castings the central part will be usually found hollow or porous, due to the following: The walls cooling first causes the outside to set at once, the interior cooling from the exterior inward, endeavors to shrink away from the outer crust, which resists this action; hence, the interior is kept to a greater diameter than is natural, and there being but so much metal in the entire mass, the atoms are drawn away from the central point in all directions, to supply the demand made by the metal in shrinking.

If the corners of the casting are sharp, the crystal formed in the iron during cooling will be abruptly turned at these parts, and continuing in this manner for some distance below the surface, create a portion weaker than the rest, or a line of fracture, and a breakage is liable to occur at these points. For these reasons and

also to permit a free flow of metal without breaking the corners of the sand, there should be no abrupt corners either external or internal made in patterns.

With a flat plate on a surface of sand, the top part cools first, as it is open to the air, so that the plate becomes convex on the top, due to the later contraction of the bottom part.

In a hollow cylinder, the heat can not pass through the core as quickly as it can from the outside, so the latter cools first and the cylinder becomes barrel-shaped, due to the after contraction of the interior. On this account hollow cylinders frequently have an iron tube through the core, through which cold water is made to circulate.

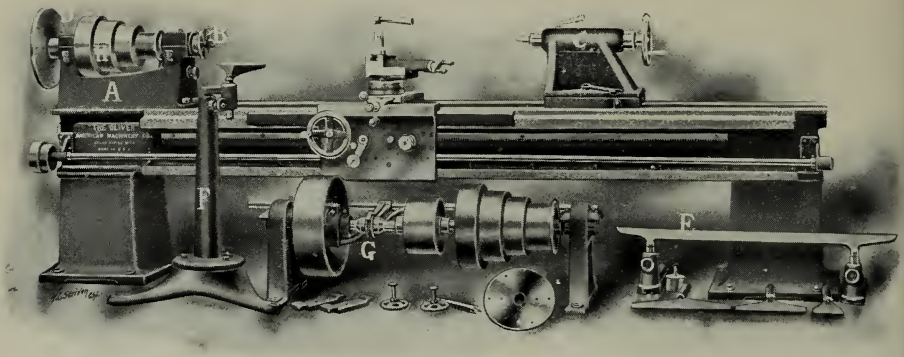


FIG. 11.

A thin-rimmed pulley will cool last at the central hub, producing a compressive strain in the rim, and a piece broken out from the rim could not be returned. This condition is improved by giving the pulley curved radial arms, instead of straight arms, thus giving an elasticity to take the strain from the rim.

Pattern-shop Tools.—From the nature of the work done in a pattern-shop, largely work of original ideas or particular shapes or adaptations, it is apparent that the use of special tools or appliances can not be indulged into any great extent, and much dependence is placed upon hand or bench work, on account of the varied nature of pattern work, and the finish required, while the time consumed frequently does not exceed that for setting a machine.

The following power or machine tools are usually found in a well equipped pattern-shop, in an engine and ship building plant:

Wood lathes,
Face lathes,
Saw benches or circular sawing machines,
Band saws,
Hand planer and joiner,
Wood trimmers,
Tool grinders,
Jig saw.

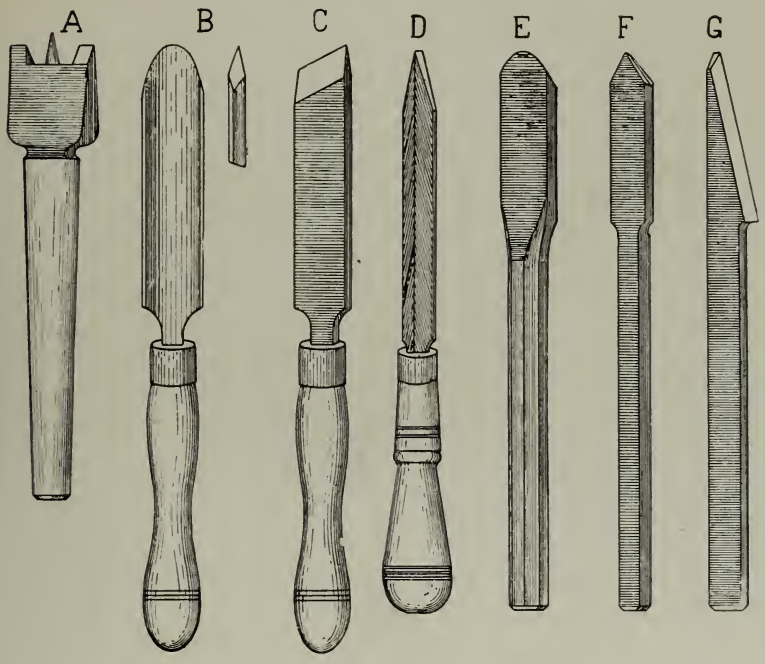


FIG. 12.

In other shops less pretentious, a lathe, saw bench, jig saw and grindstone are frequently the only equipment found necessary.

Of the above, the *wood-turning lathe* may be considered indispensable and is constantly employed. In Fig. 11 is shown a pattern-maker's lathe; the main framing is of iron planed true on the top with grooves and ways for the sliding head and rest.

A is the head stock with face plate *B*, and *C* is the tail stock. An additional face plate is usually fitted at the opposite end of the

mandrel at *D* for turning large pieces of work. *E* is the steady rest for supporting the turning tool and *F* the portable tripod rest. The counter-shaft *G* is suspended overhead from the ceiling, and is connected by belting to the cone pulley *H*.

For chucking appliances *A*, in Fig. 12, represents a forked center used in turning work between the centers. The taper post fits into the lathe mandrel; center *A* keeps the work true, while the flat

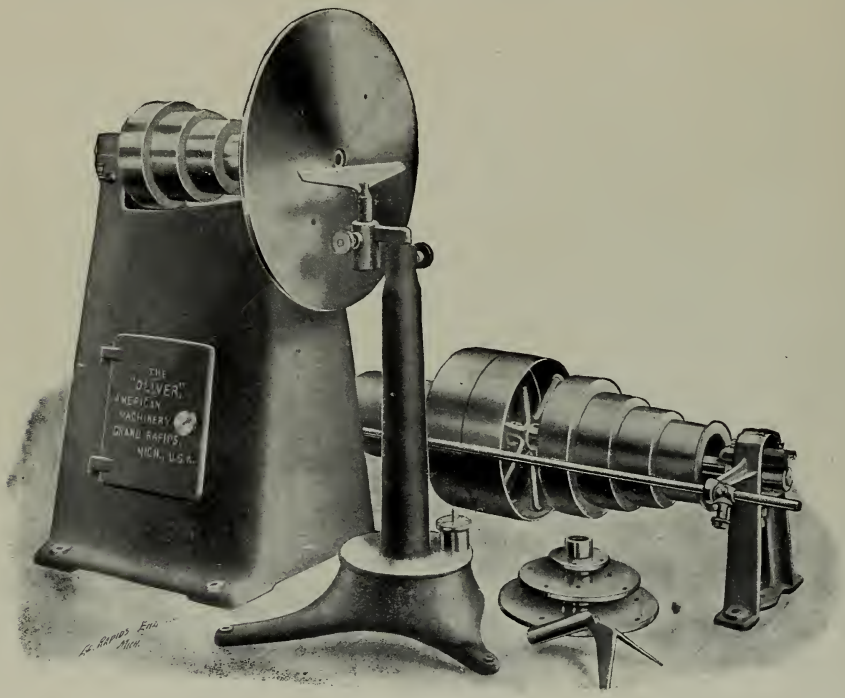


FIG. 13.

wedge-shaped prongs do the driving. For the opposite end an ordinary lathe center is used in the tail stock.

For holding work independent of the back center, for facing, boring, etc., chucks are used, the simplest form is a wooden built-up face, and secured to the face plate of the lathe by bolts or screws.

The turning tools employed are the following in various sizes, and shown in Fig. 12. The *turning gouge* for roughing out is

shown at *B;* the *skew chisel* for finishing plain work and dressing down the end of collars or shoulders at *C;* the *parting chisel* at *D;* the *round-nose chisel* for finishing hollows at *E,* and the *diamond-point* tool at *F.* Shapes other than the above may be improvised for the particular type of work.

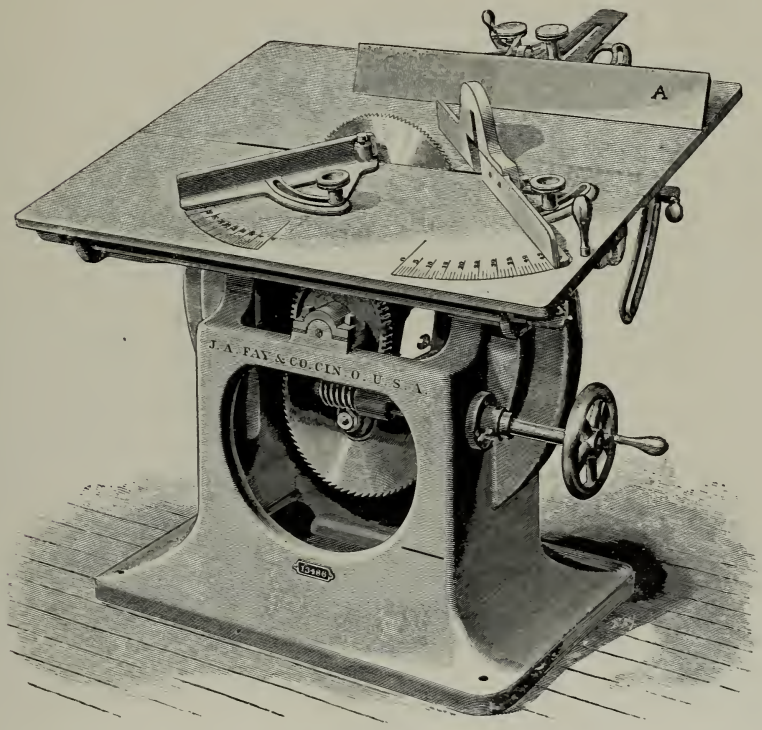


FIG. 14.

A *face lathe* is shown in Fig. 13, and is used for turning and facing pieces of large diameter. The work is secured on the face plate; the operator stands in front of it, and not at the side, as in the previous lathe, and thus is more conveniently located for the work when face-work and inside-turning are required. This lathe is provided with tool rest and stand, and overhead counter shafting.

The saw bench is adopted for a great variety of work, but it is

mainly applied to roughing out purposes, for slitting and cutting at any angle required. In Fig. 14 is shown the double circular sawing machine or saw bench. Two saws are used, one for ripping and the other for cross cutting, both driven by one belt from a countershaft, so arranged that when either saw is in position to work, the other remains at rest. The saw is adjustable to cut all thicknesses within its size. The table can be adjusted from the

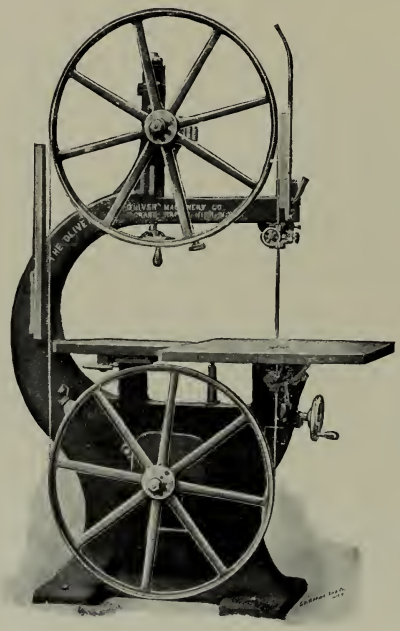


FIG. 15.

horizontal position to an angle of 45°, and is divided into two parts, the right-hand section being stationary and used for ripping purposes, the ripping fence or guide being adjustable and shown at *A*. The left-hand section is for cross cutting purposes; it is movable upon rollers and guided by plane surfaces, thus retaining its position parallel to the saw. The two graduated quadrants on the front table, with adjustable fences, enable right and left angles to be cut without re-adjustment. The counter-shaft is usually placed beneath the floor.

The *band saw,* Fig. 15, is of great utility, performing the work required of it with exactness and rapidity. It can perform much of the duty of a circular saw, and is valuable in the case of teeth of wheels, segments, etc., from the quality it possesses of cutting true and exact to line. The table can be tilted and adjusted for cutting bevels or drafts.

The *hand planer and jointer,* Fig. 16, is designed for making glue joints, straight or hollowing, for chamfering, beveling, truing up, taking out of wind, etc. The cutting knives are carried on the revolving head driven by belting, while the work is fed along the table against the beveling fence *A,* which is adjustable by means

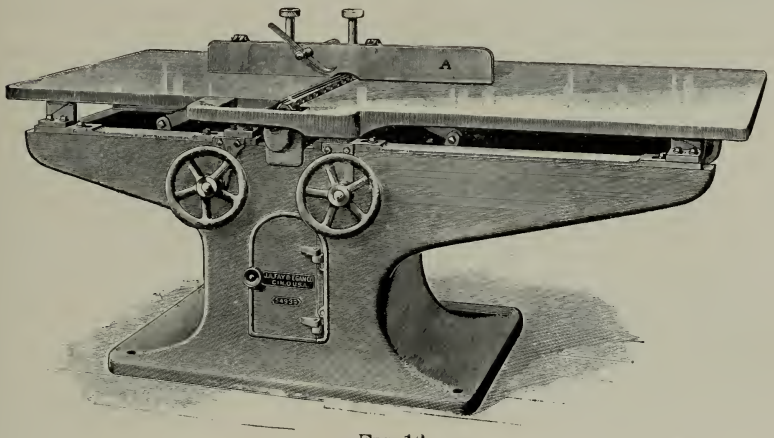


Fig. 16.

of a clamp operated by a screw, holding the fence to any desired bevel.

The *trimmer,* Fig. 17, is a valuable addition to the pattern-shop and does away with much of the laborious work of the chisel in cutting end-ways of the grain. For building up segment work it is very desirable, cutting as straight and clean as wood can possibly be cut.

The remaining items in the power equipment can be seen and operated in the pattern-shop of the Engineering Department. A necessity in every pattern-shop is hot glue, and the usual medium of keeping it heated and ready for use is steam. The heater consists of two receptacles, Fig. 18, the one forming the outer casing

containing water, while the glue pot is inserted in the casing, and the water heated by contact with a steam ring at the bottom of the outer casing. In the absence of steam the water is heated from a gas jet or spirit lamp. Glue pots are also heated by an electric current, the heater is a coil heater of flat or cylindrical coils and to conform to the shape of the water casing. Both types are in use in the Engineering Building. The proper application of glue is

FIG. 17.

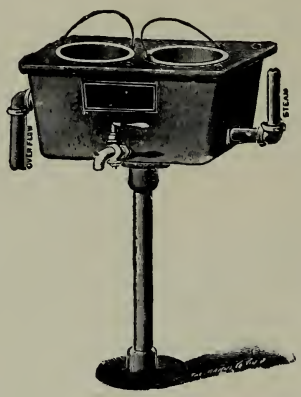


FIG. 18.

important, as defective gluing will soon show itself and greatly impair the value of the pattern-maker's work.

The hand tools used by the pattern-maker are numerous, and it is unnecessary to go into any elaborate description, as midshipmen are brought in contact with their use daily, in practical instruction in this department during the drill periods. In Plates I and II are given an illustrated table of all the hand tools used at the bench or on the lathe, comprising the following:

Fig. 1. Four-fold two-foot rule.
2. Shrinkage or contraction rule.
3. Carpenter's steel square, graduated.

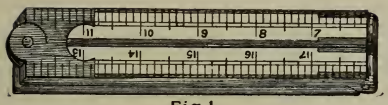


Fig. 1.

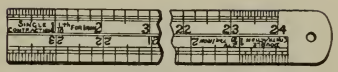


Fig. 2.

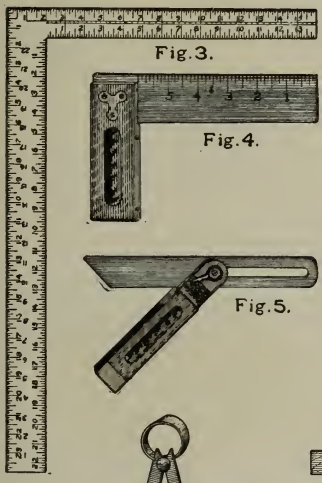


Fig. 3.

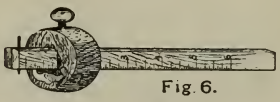


Fig. 6.

Fig. 4.

Fig. 7.

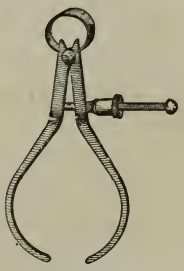


Fig. 8.

Fig. 5.

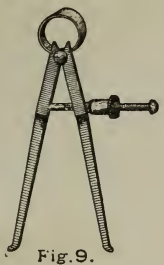


Fig. 9.

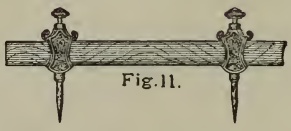


Fig. 11.

Fig. 10.

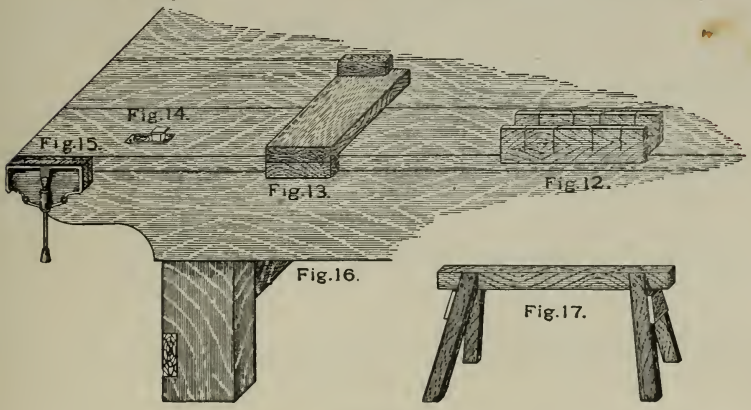


Fig. 16.

Fig. 17.

PLATE I.

Fig. 4. Try square, rosewood handle, steel blade.
5. Sliding T. bevel for marking and testing oblique angles.
6. Marking gage.
7. Wing compasses.
8. Outside calipers.
9. Inside calipers.
10. Spirit level: (a) for horizontal, (b) for vertical surfaces.
11. Trammel or beam compass.
12. Miter box.
13. Bench hook.
14. Bench stop, made in many varieties.
15. Bench vise.
16. Bench, hardwood top, preferably maple.
17. Saw horse.
18. Iron clamp.
19. Hand screw.
20. Rip saw teeth.
21. Cross-cut saw teeth.
22. Hand saw.
23. Compass saw.
24. Back saw.
25. Claw hammer.
26. Wooden mallet.
27. Jack plane: (a) stock, (b) top, (c) sole, (d) handle, (e) wedge, (f) iron.
28. Smoothing plane.
29. Rabbet plane.
30. Brace.
31. Bit drill.
32. Center bit.
33. Auger bit.
34. Rose counter sink.
35. Draw knife.
36. Spoke shave.
37. Chisel.
38. Gouge.
39. Screwdriver.

Fig. 18.

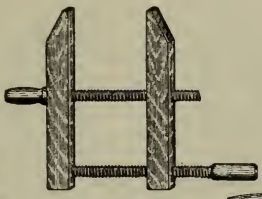


Fig. 19

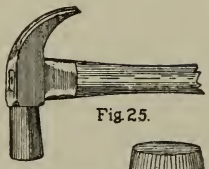


Fig. 25.

Fig. 20

Fig. 21

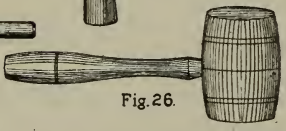


Fig. 26.

Fig. 22

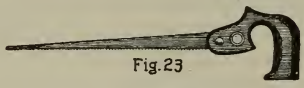


Fig. 23

Fig. 24.

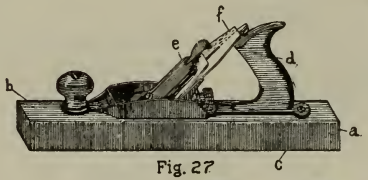


Fig. 27

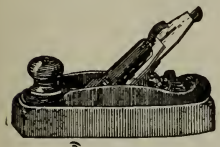


Fig. 28

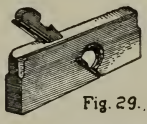


Fig. 29.

Fig. 31.

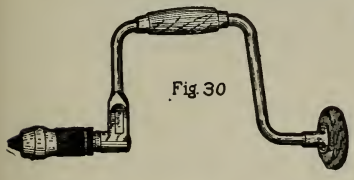


Fig. 30

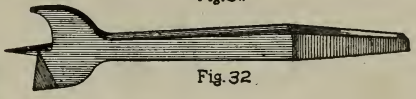


Fig. 32

Fig. 33.

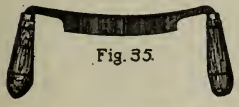


Fig. 35.

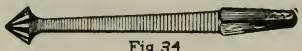


Fig. 34

Fig. 36.

Fig. 37.

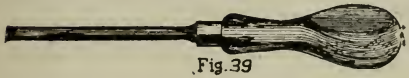


Fig. 39

Fig. 38

PLATE II.

In addition to the above there are oil stones, grind stone, brad awls, gimlets, brad punches, pliers, pincers, rasps, and files.

The workbench is made of hard wood and care should be taken to preserve a smooth and clean top; saws, chisels, nails, and other sharp tools should never cut into the bench. The tools should only be used for the purpose they are intended, try squares not as hammers, nor compasses as boring tools. In the shop aim at *accuracy,* which implies the marking and cutting; second, the *finish;* and third, *quickness* of execution.

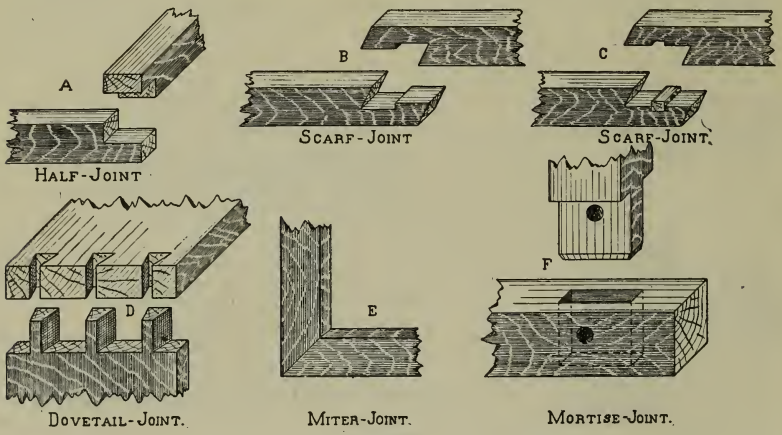


FIG. 19.

Common Joints.—In Fig. 19, *A* shows a *half-joint, B* and *C* *scarf-joints, D* a *dove-tail-joint, E* a *mitre-joint,* and *F* a *mortise-joint.*

A Board-foot.—A board-foot is equal to 144 square inches of board surface, one inch or less thick; for instance, a board 12″ x 12″ x $\frac{1}{2}$″ thick = one board-foot, as does also a board 12″ x 12″ x 1″ thick, while one 12″ x 12″ x $1\frac{1}{2}$″ thick = $1\frac{1}{2}$ board-feet. This is the method in common use for the purchase of lumber.

A good pattern-maker will so arrange his patterns as to reduce as much as possible the expense of moulding, and to give the least trouble in the foundry; as little as practicable of the pattern should be in the top box, as this part of the mould receives the worst treatment.

Pattern Building.—A sufficient number of full-sized views of the pattern, core prints, and required data are drawn out on boards, to be used as templates from which to work. In this full-size drawing a proper allowance is made according to the shrinkage rule, and a sufficient amount of taper given to all faces parallel to the direction in which the pattern is to be withdrawn from the sand. Patterns carved out of the solid are more likely to warp, so that moderately large patterns are made up of layers of wood well glued together, the layers being first truly planed, the different parts made to "break joint," and then, when thoroughly dry, the whole worked down to the desired shape and size.

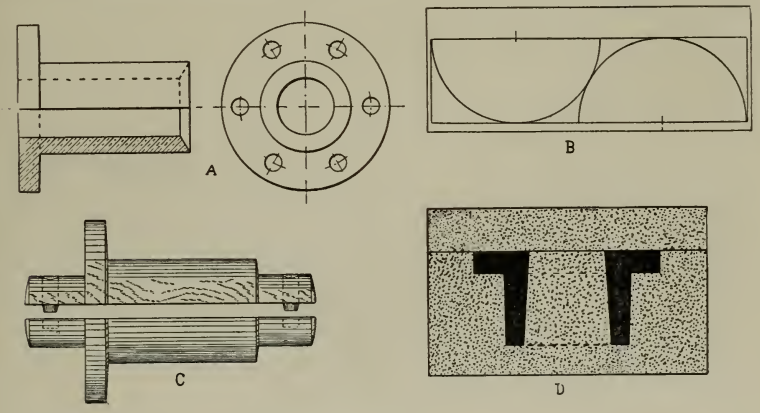


Fig. 20.

One of the simplest examples of pattern-making is that of the stuffing-box gland for a piston rod, Fig. 20, and is constructed as follows: Plane up a piece of wood and on it scribe two semi-circles, Fig. 20-B, to represent the two half flanges, larger and thicker than the flange called for in accordance with the "shrinkage scale," as will be done in all succeeding operations. Draw a straight line across the lathe chuck through its center. Cut out the two half flanges and set their diameters to this center line in order that when they are turned down they will part in the center. Screw them to the chuck in this position, turn them as a single piece to the required diameter, and dress the face to the necessary thickness. A circle of the size of the central hole is next scribed on the face

of the flange, and with a narrow chisel the hole is cut out and finished with a diamond-point or side-tool. The necessary draft for withdrawal from the mould is given by making a slight taper from the hub-end to the rim.

To Make the Body of the Gland.—Take two pieces of wood, each of sufficient length to make up the body of the gland, core print, and about a half an inch at each end for dressing and finishing up. Plane these pieces truly on one face, make them of equal thickness, and peg or pin them together by clamping the face surfaces against one another, then boring two holes through the top piece and partly into the bottom piece. The pins or pegs are driven through one-half the pattern and the projecting ends tapered off to fit into the other half. The pegs then inserted, the two halves are fastened together, usually with a thin wash of hot glue, for about a half an inch at the ends and held together by a clamp until dry. For heavy work this is supplemented by screws or staples.

Next mount this work in the lathe, carefully setting the lathe centers exactly in the joint. Work off with a skew chisel the different length measurements for the body, the thickness of the flange, the length of core prints, and turn down the body to size, the adjacent part to fit tightly the hole in the flange and the core prints turned to the length and diameter desired. The flange is next fastened to the body by gluing it and by the use of finishing nails. The final process consists in sand-papering and smoothing, the application of two or more coats of spirit varnish, thus giving a surface impervious to water, and the smoothness so necessary for easy extraction from the sand. Especial care should be taken on all patterns to secure a proper draft or draw, so that they may be readily and easily withdrawn.

Where the length is long compared with the diameter, or in short sections where the inner diameter approaches the outer diameter, the horizontal position for casting, as shown above, is better.

If the gland is short, the pattern may be made in one piece and also makes its own core in green sand, as in Fig. 20-D. In this case it is cast vertically, a taper hole should be made in the pattern. The separate dry-sand core is stronger; the hole, if required to be bored parallel, can be more easily done by dry-sand coring; the

casting will be lighter, since less metal must be cut out and consequently cheaper, as castings are priced by the pound.

Reference has been made in the above to cores, prints, etc. A *core-print* is a tapered boss on a pattern with which an indentation is formed in the sand of the mould for the reception of the core.

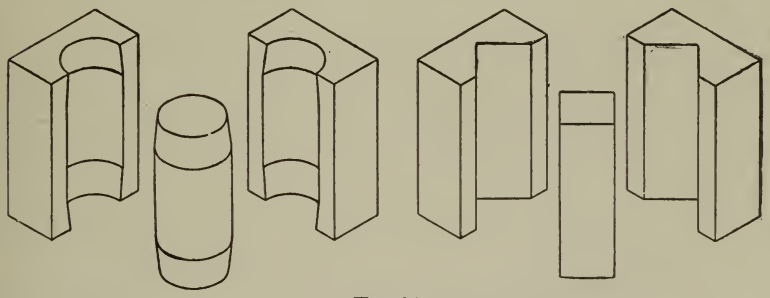


FIG. 21.

The core is the inner portion of the mould, partly or wholly surrounded by metal. It is usually made of a mixture of rock sand and sea sand, and after being dried or baked is placed in the mould in proper position. The object of a core is to make a recess or hole in the casting that is not possible with the pattern alone.

The *core-box* is a general term applying to all devices for making cores, but more properly those which the pattern-maker constructs

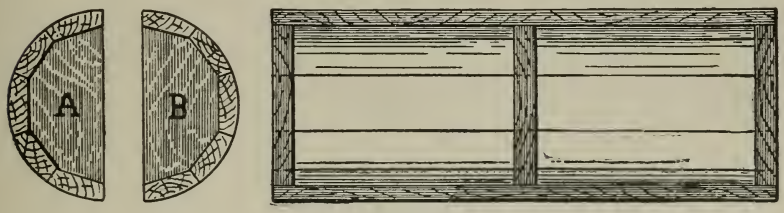


FIG. 22.

out of wood. Fig. 21 represents the cores and boxes for cylindrical and rectangular cores.

Tee Pipe and Joint Work.—For small pipes, the patterns are cut out of the solid, but for the larger pipes they are built up. In Fig. 22 is shown the method of building up for a straight pipe. The ends are polygon discs, made in halves and also supporting

discs at intermediate points. Pieces similar to barrel staves are secured to the sides of the discs by glue and screws and form the outer part of the pattern. The two surfaces at *A* and *B* are made true planes, as in the preceding example, pegged, temporarily secured together, centered in the lathe, and turned down to the required size. The flanges are prepared and secured in the same manner as for a gland, or fitted as shown in Fig. 23.

For a *bend* the strips of wood can not readily be bent to the shape; they are consequently built up in sections, as shown in Fig. 24, worked down by the gouge and spokeshave and tested from time to time by the template *C*, until the pattern is brought down to gage.

For a *tee piece* or a pipe pattern with branches, the following is

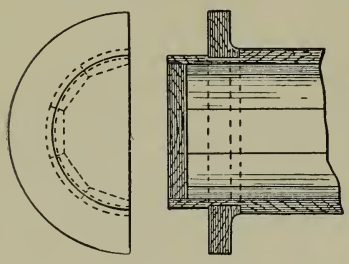


FIG. 23.

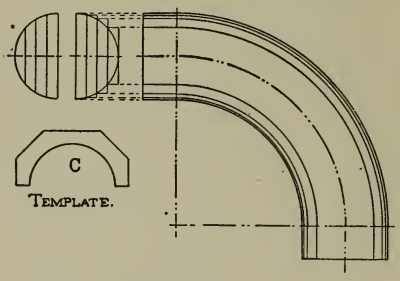


FIG. 24.

a simple and quick method: If the body and branch are of equal and uniform diameter, cut the end of the branch *A* on either side at 45 degrees with the center line. The line made on the circumference of the branch by this cutting will be that of the junction with the main body, and the body and branch can be cut to this line. See Fig. 25.

If the branch is smaller than the body, the method of obtaining the curve of intersection has already been taught in the course in Descriptive Geometry. As a review take the following practical method: A paper pattern is usually made to mark off the line of junction. In Fig. 26, lay down a plan, and a section of half the body and branch, as at *D* and *E;* divide the semi-circumference *E* into equal parts. From the intersections project lines to intersect the curve of the body *D*. Place a paper *C* as shown, and on it draw

two parallel lines OY and OV separated from one another by a distance equal to the circumference of half the branch E. Divide this distance into the same number of parts as we have divided the semi-circumference of E, draw verticals intersecting the line on the paper C, at 0′-1′-2′-3′-4′-5′-6′. A curve drawn through these points gives the developed curve of intersection of the branch with the body, and will answer for both halves since they are alike. Having obtained, by means of the paper, the curve of intersection, it can be laid off on the branch and body, then cut out, and the rest of the pattern proceeded with as in the preceding example.

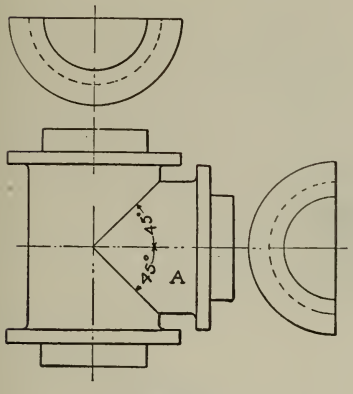


FIG. 25.

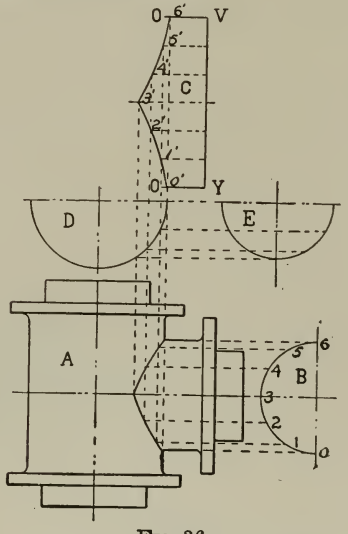


FIG. 26.

If the branch is fitted diagonally to the body of the pattern, the plan is somewhat similar to the foregoing and has already been explained in practical work on the intersection of solids in Descriptive Geometry.

Problems.—Show the method of obtaining the curve of junction for a pipe pattern, diameter of body 6 inches, diameter of branch 4 inches, and the angle of the branch 30°.

When there is much occasion for fitting branches to plain patterns, a trammel, such as shown in Fig. 27, will be found of great advantage. The description and application are as follows: It

consists of a turned rod *A*, and upon it the sliding tube *B* with a head. The head carries a radius rod *C* at right angles to the axis of the spindle *A*, which is adjustable to varying radii, and with one end fitted with a vertical scriber, the scriber and radius bar being held by clamps for fixing in any position desired. Taking a planed board, a center line is scribed upon it, and on this line is placed the spindle, so that its axis intersects it. A cradle, such as a V block, is used to carry the branch, and is set so that the apex of the V comes directly over the center line. The point of the scriber is now set out from the axis of the spindle, a distance equal to the radius of the body, and the top of the branch, as it lays in the V,

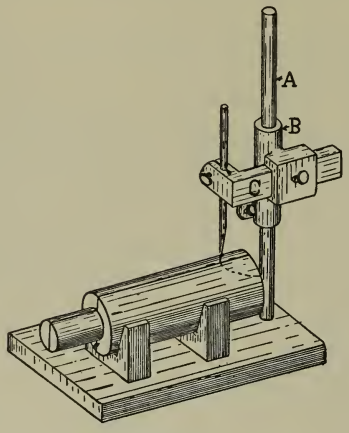


FIG. 27.

is marked for the cutting-out curve, the point of the two halves standing vertically. This makes one side of the branch; for the opposite side, the branch is turned upside down and the operation repeated.

This device can be used whether the branch is set at right angles to the body of the pattern, or obliquely. In this latter case, instead of the branch being set square with the spindle, it is set at the angle at which it is to stand with the body of the pattern, and the curve scribed on the work as before.

The work is then taken to the band saw, cut to the lines marked, and, if carefully done, but little additional fitting is required to

make it suitable for attachment to the main body of the pipe pattern. Flanges, core-prints, and core-boxes are fitted up as before.

Making a Screw Propeller from a Pattern.—If a three or four blade propeller is required, and is to be cast entire with the hub, a pattern of one blade is in general all that is needed, in which case the moulder rams up one blade at a time. Drawings of the screw are sent out from the drafting-room of the general style shown in Fig. 28, and containing all the information necessary for dimensions, type, etc., required by the pattern-maker and moulder. The method of making these drawings is shown in the advanced course in drawing for the 3d class, while the design of the screw is illustrated in the course of Machine Design in the 1st class.

Taking for illustration the U. S. Navy type of the modified Griffith's screw, the drawings, as in Fig. 28, having been furnished, the first point is the making of the pattern. It will be noticed that the screw, instead of being cast in one piece, is made in separable parts, each blade being made separately, has a flange cast on the root, by means of which it is bolted to the hub. This is the practice employed in the Navy, and generally in ocean-going steamers, and possesses the advantage of enabling one or more injured blades to be renewed without removing the whole screw, while the pitch is capable of slight variation, but it is more expensive in first cost. The following description is given as an aid in working out the pattern of a blade in the pattern shop, during the practical drills.

In making the pattern of the blade there are a number of methods, the simplest and most accurate probably being as follows: Fig. 28 shows the plan of one blade and contains sections at five points on the radius of blade, thus giving the shape and thickness of the blade at those points, and is employed in laying out the different shapes of the boards used in developing the pattern. The pattern of the blade is built up of pieces of parallel thickness with one edge square with the sides. Obtain a surface board longer than the radius of the screw and sufficiently large to lay off to full size the different dimensions required in obtaining the different parts.

Having determined the thickness of the strips of lumber to be used, the number is known. In Fig. 29 lay off the center line *AA*

and at right angles to it draw *BB*. From the drawings, Fig. 28, lay out full size the flange of the blade from the center *C* of the hub or shaft. Ascertain from the drawings if the face of the blade

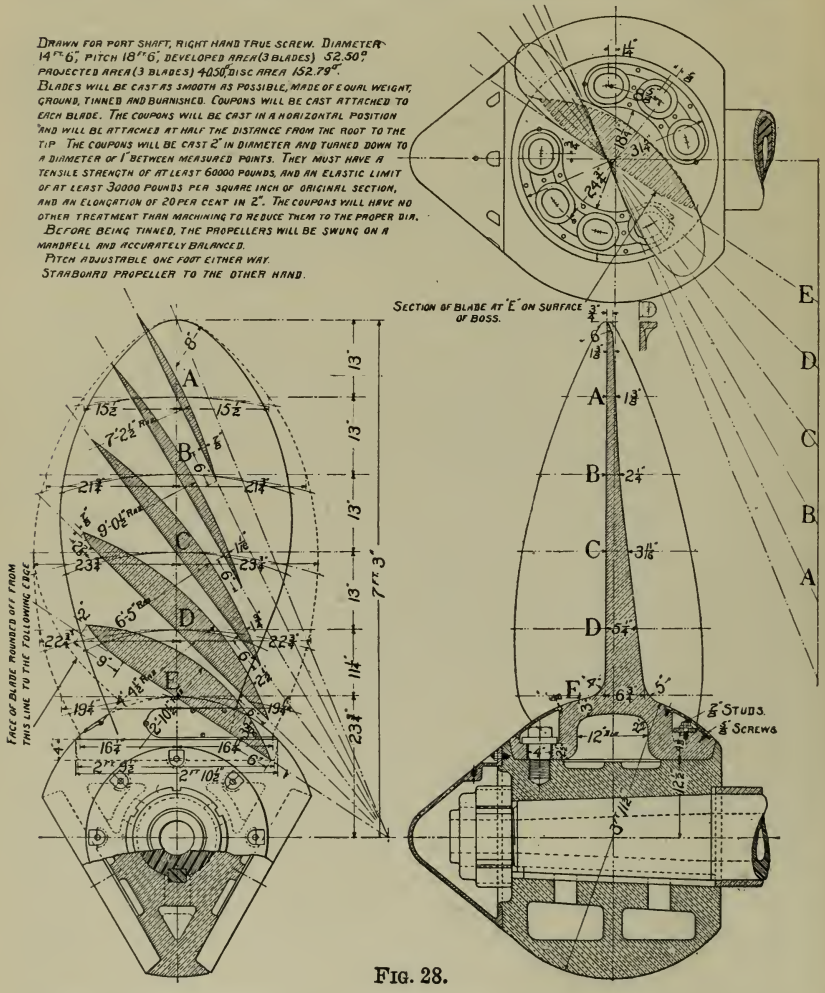
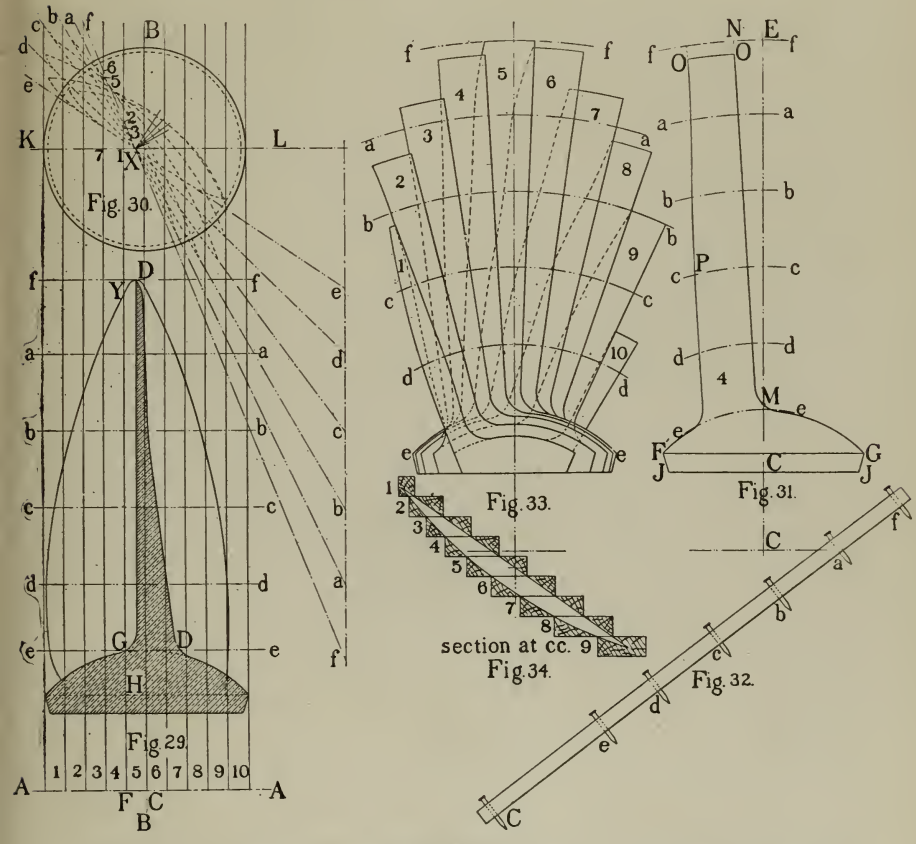

DRAWN FOR PORT SHAFT, RIGHT HAND TRUE SCREW. DIAMETER 14FT 6", PITCH 18FT 6", DEVELOPED AREA (3 BLADES) 52.50 SQ. PROJECTED AREA (3 BLADES) 40.50 DISC AREA 152.79 SQ.
BLADES WILL BE CAST AS SMOOTH AS POSSIBLE, MADE OF EQUAL WEIGHT, GROUND, TINNED AND BURNISHED. COUPONS WILL BE CAST ATTACHED TO EACH BLADE. THE COUPONS WILL BE CAST IN A HORIZONTAL POSITION AND WILL BE ATTACHED AT HALF THE DISTANCE FROM THE ROOT TO THE TIP. THE COUPONS WILL BE CAST 2" IN DIAMETER AND TURNED DOWN TO A DIAMETER OF 1" BETWEEN MEASURED POINTS. THEY MUST HAVE A TENSILE STRENGTH OF AT LEAST 60000 POUNDS, AND AN ELASTIC LIMIT OF AT LEAST 30000 POUNDS PER SQUARE INCH OF ORIGINAL SECTION, AND AN ELONGATION OF 20 PER CENT IN 2". THE COUPONS WILL HAVE NO OTHER TREATMENT THAN MACHINING TO REDUCE THEM TO THE PROPER DIA.
BEFORE BEING TINNED, THE PROPELLERS WILL BE SWUNG ON A MANDRELL AND ACCURATELY BALANCED.
PITCH ADJUSTABLE ONE FOOT EITHER WAY.
STARBOARD PROPELLER TO THE OTHER HAND.
SECTION OF BLADE AT 'E' ON SURFACE OF BOSS.
FACE OF BLADE ROUNDED OFF FROM THIS LINE TO THE FOLLOWING EDGE
A
B
C
D
E
5/8" STUDS.
5/8" SCREWS.

FIG. 28.

is back from the center line *BB*, if it is on the center line, or if it has a rake, and then draw the face-line accordingly.

From the end elevation, Fig. 28, it is seen that five thickness strips or sections are taken; cut *BB* by parallel lines at the radii

these sections are taken, *a-a, b-b, c-c,* etc., and on the lines lay off the thickness of the blade from the face-line at their respective radii, and sweep in the line *DD* through these points, with the fillets at the root, thus obtaining a full-size vertical section through the middle of the blade, Fig. 29.



In Fig. 30, lay out the plan of the blade and hub, and since the face of the blade is parallel to the center line *BB*, and distant from it a known amount, in this case $1\frac{3}{8}$ inches, all the pitch lines must pass through this point *X*, just determined. At the angles shown by the pitch lines in the end elevation, draw these pitch lines through *X* in the plan view, and on these lines as bases lay off the sections through the blades at the radii taken in the end elevation.

The side elevation of the blade is next determined full size by projecting down from the extremities of the sections shown in the plan view to intersect their corresponding lines *a-a, b-b, c-c,* etc., in Fig. 29, thus determining the contour of the blade *eDe.*

In Figs. 29 and 30, lay off the thickness of the material to be used, in equal spaces parallel to *BB* and numbered 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10. In Fig. 31, draw the center line *CE* on one of the boards previously laid out for the manufacture of the segments to be used in the construction, and from the point *C,* the center of the shaft, scribe arcs corresponding to the radii *a-a, b-b, c-c,* etc., in Fig. 29. As this will be done with every segment used, accuracy and facility will be increased by taking a light batten, Fig. 32, and driving through it sharp-pointed nails to indicate the location of the center of the shaft, and the radii *a, b, c, d,* etc., to be used. By fixing the center nail to each segment board and swinging the batten the arcs can be quickly and accurately scribed on each board.

To Cut the Segment to Shape.—Taking any segment board, such as No. 4, lay off the base line of the flange from the center *C,* Fig. 31. With *C* as a center and a radius equal to *FG* taken from Fig. 29, scribe an arc *F'G'.* To determine the length of this arc, from *C* lay off a distance *FH,* taken from segment No. 4, Fig 29, and through this point draw the horizontal line *F'G',* the intersection of this line with the curve just drawn gives the points *F'-G',* and the dimensions of the rounding part of the flange for this segment. For the lower part, or base of the flange, lay off on the base line of the flange, Fig. 31, the distance *C'J* on each side of the center line and connect the points *J-F'* and *J-G',* thus obtaining the contour of the hub for this segment.

In the above the distance *C'J* for each segment is the distance from *KL,* Fig. 30, to the intersection of the segment under discussion, with the projection in Fig. 30, of the bottom or base of the flange.

For the contour of the blade, lay off from the center line *CE,* Fig. 31, on the arc *a-a* the distance from the line *KL,* Fig. 30, to the point 2, the intersection of the face-edge of the section at *a-a* in Fig. 30, with the edge of the strip 4, similarly on the arc *bb* lay off the distance 1-3 from Fig. 30, the intersection of the face of the blade section *b-b* with the edge of the segment No. 4. Again meas-

ure the distance of the intersection of the face of the section with the edge of the segment No. 4 from *KL* and lay this off from the center line on the arc *cc*. Bend a sweep through these points and draw the line *MN*, giving the face-edge of the blade for the element No. 4. With a true screw and no rake, this line will be a straight line.

To obtain the back edge of the blade at the section *b-b* for the same segment, measure off the distance from *KL* to point 5 in Fig. 30, the intersection of the back of the blade with the segment *b-b*, and lay this off from the center line *CE* on the arc *bb*, Fig. 31, thus obtaining one point for the back of the blade. Similarly, take the distances of the intersection of the back of the blade at sections *c*, *d*, and *e*, with segment No. 4, and lay them off from the center line on the arcs *c-c*, *d-d*, and *e-e*, respectively. Sweeping a curve through these points and we obtain the contour of the back of this element. From the center *C*, Fig. 31, with a radius equal to *CY*, Fig. 29, the intersection of the edge of the blade with segment No. 4, draw the arc *OO*, thus obtaining the length of this segment.

When the end of the segment passes beyond the pitch-angle line as in segment No. 4, section *a-a* in the above, extend the next greater pitch-angle line, in this case, the one at the tip of the blade *f-f*, and measure the distance from *KL* to the intersection of this pitch line with segment No. 4, equal to 7-6. Transferring this distance to *f-f* on Fig. 31 from the center line *CE* we obtain the true face from section *a-a* to section *f-f*.

Connect up face and back of the blade by fillets to the circle of the hub, previously drawn, and saw the piece out to the outlines marked, and we obtain the size and shape for the segment piece No. 4.

All the segments are laid out in a similar manner to the above, obtaining the distances from Figs. 29 and 30, and laying them off on Fig. 31. Saw out to these lines on the different segments and you are then ready to glue them together. In gluing up care must be observed to see that the work is true. This can be tested by taking a straight edge and holding it out on the center line *CE* and measuring over to the different segments, as at *P* on arc *c-c*, segment No. 4, Fig. 31, and comparing it with the distance 7-5 as laid down in Fig. 30. If these measurements correspond, the pitch is true. Or a simpler method is as follows: Measure at each sec-

tion *a-a, b-b,* etc., the distance of the driving face of the screw from its center line, and lay it off on the corresponding section of the next consecutive segment, then on assembling the segments for gluing up, if each segment is laid so that its driving edge is directly on the points marked at the succeeding segment and secured in that position, the pitch will be found true and the pattern will correspond to the drawing.

After gluing, the projections of the segments are faced off to a feather edge, and when smoothed up the pattern shows a finished surface, for the face and back of the blade, together with the flange.

In facing off the face and back of the blade pattern, they are finished down to the lines formed by the joints of the different segments, as illustrated in Fig. 34. The configuration of the blade is the next process, and can be laid off directly from the center line on the face of the pattern; or a template of the correct shape made, and the face of the pattern marked by it. The contour having been marked, the material beyond this boundary is cut away and the edges finished by working down the back to an easy curve, where it joins the face. The pattern is then sand-papered, given several coats of shellac, and is then ready for the moulder.

In moulding, each blade is separately made in its flask, composed of a cope and drag. The pattern is laid flat in the drag with one-half of the flange projecting above the top, the sand is well tamped in under the blade, and parting sand sprinkled over the face. The cope is put in place, filled with sand and tamped, gates and risers made, and the metal poured.

The pattern for the hub is made a model of the casting desired, but constructed in parts, so that it can be readily taken apart, in order to release the interior parts and permit their withdrawal without breaking down the mould. The parts being built up according to the drawing, the spherical form is given by working off the pattern by hand or by turning in a lathe. For the core-prints to be used, that for the tapered core forming the hole for the shaft is permanently fixed to the pattern, the prints for the recesses on the three sides, where the flange is connected to the hub, are removable and held by pins, so that the pattern can be removed separately. In moulding, cores are then inserted in the impressions made by these prints before the main-shaft core is set.

CHAPTER IV.

MOULDING AND CASTING.

Iron-casting.—Owing to its low cost, its strength, and the ease with which it can be cast into various forms, cast iron is extensively used in all engineering structures.

The different varieties of cast iron are distinguished by the color and general appearance of the fracture when newly broken. Commercially there are eight numbers used to distinguish the different grades. From one to three constitute *grey* iron, which is soft and tough, easily filed and turned, and is much used for foundry work. Numbers 4 and 5 are called *mottled* iron, much stronger than the preceding, and is also a strong foundry iron. The higher numbers are graded among *white* cast iron, silvery in color, hard and strong, and much used for conversion into wrought iron or steel, nearly all the contained carbon being chemically combined. The qualities of white cast iron are brittleness, so that it is difficult to be turned in a lathe or filed, and unfit for machinery; it is either granular or crystalline, exceedingly hard, and is not well adapted for foundry work, since it does not flow well, and is pasty in consistence.

The strength and quality of cast iron is improved, and its value for castings increased, by mixing with it a proportion of good scrap iron varying from 30 to 40 percent. For very tough castings wrought iron turnings are sometimes mixed with the pig in the cupola.

The rate at which the cooling takes place also affects its characteristics almost to as great an extent as its chemical properties. If grey iron be melted and then rapidly cooled in contact with a metallic surface, it will be to a greater or less depth converted into white iron. This treatment is known as *chilling,* and the product has all the characteristics of white iron; is extremely hard, has great tenacity, and is very brittle compared with the original iron from which is was produced.

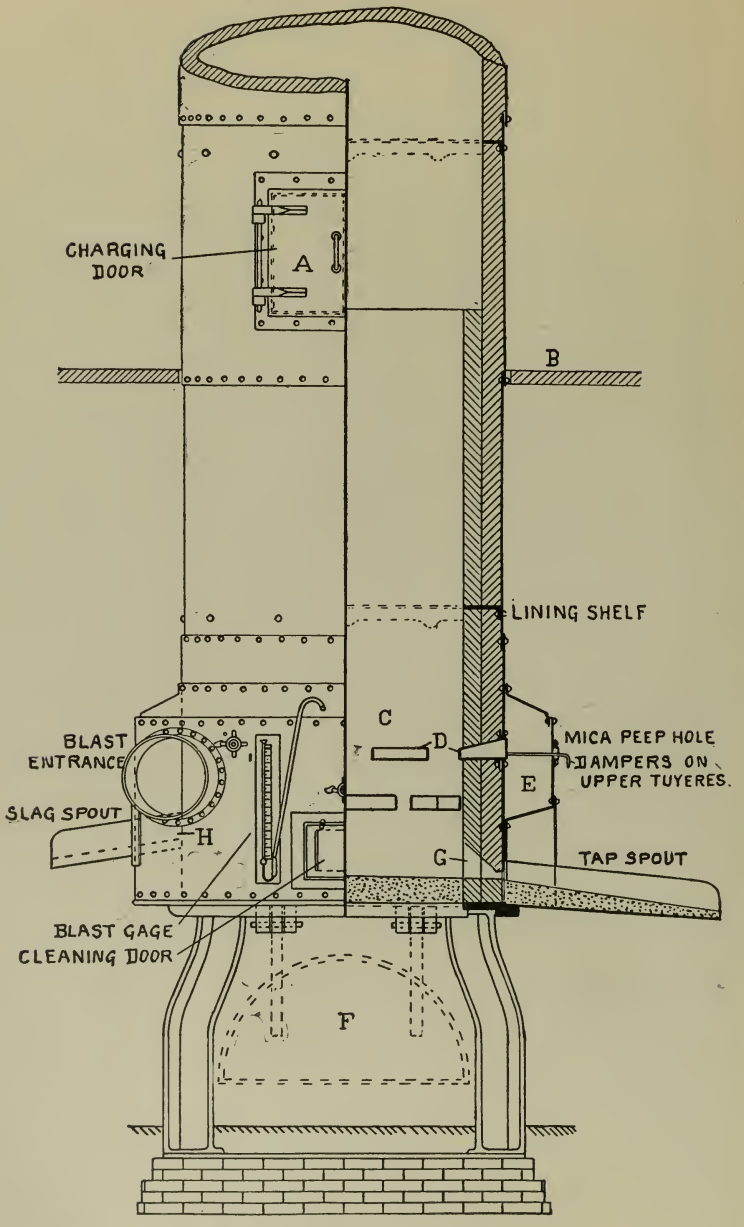

CHARGING DOOR
A
B
LINING SHELF
C
D
MICA PEEP HOLE
DAMPERS ON UPPER TUYERES.
E
BLAST ENTRANCE
SLAG SPOUT
H
G
TAP SPOUT
BLAST GAGE
CLEANING DOOR
F

FIG. 35.

The Cupola.—In order to melt the pig iron for use in casting, a *cupola furnace* is used. Those in common use usually consist of an external wrought iron shell, inside of which is built a lining of fire-brick set in fire-clay, and the whole supported on four iron columns, which allows for the dropping out of the entire contents of the cupola at once.

In Fig. 35 the usual construction is shown, where *A* is the *charging door, B* the *charging platform, C* the *body* of the melting furnace, in which layers of coke or coal and ore are alternately charged through the *charging hole,* during the progress of the operation of melting. A ring of *tuyeres* is arranged in the lower part of the cupola shown at *D,* and communicating with an annular casing or ring *E,* called the *wind box* or *air chamber,* into which the *blast* pipe enters, *F* is the *bottom drop* consisting of flap-hinged doors. As the iron is melted it falls to the bottom, and is run out from time to time into ladles from the *tapping hole G* and spout, carried to the moulds, and the tapping hole then replugged with clay. In the metal a certain amount of *slag* is produced; this slag being the fused compounds of the silica and alumina in the lining, together with the dirt and impurities in the iron and fuel. A certain amount of this slag is beneficial in protecting the molten iron at the bottom, from the action of the blast, and when formed in too great abundance, it is blown out through the *slag hole H,* situated just below the line of tuyeres. If from dirt impurities, etc., it becomes necessary to use a flux, the amount of this slag is greatly increased. To protect the bottom from the action of the melted metal which collects at that part, it is lined with sand mixed with wet loam to give it consistency.

The top of the cupola is hood-shaped and made to conform to the size of the chimney. *B* is the *charging platform* and is the stage upon which the fuel and iron is landed for convenience in charging. It is situated just below and in front of the charging door, and the material is usually raised by means of a *steam or hydraulic elevator.*

To start and charge a cupola, the bed is covered with kindling, split plank or lumber and coke or coal, and a sufficient time allowed to get the cupola well heated up, about two hours, then the pig and fuel are alternately charged during the process.

In tapping a cupola the cupola tender has two long rods, one a pointed iron bar for piercing the clay plug or *bott* in the tapping hole, which is done as soon as the ladles are brought under the spout. As soon as the ladle is filled the other rod is used, on the end of which is the clay plug, conical in form, which is firmly pressed in the hole.

Moulding is the art of preparing moulds from plastic materials, such as sand or loam, capable of resisting the action of molten metal, and into which is run the metal, there allowed to cool and solidify into a reproduction of the pattern used.

The pattern is impressed in the sand contained in two *moulding flasks,* half the pattern in one box and half in the other. A foun-

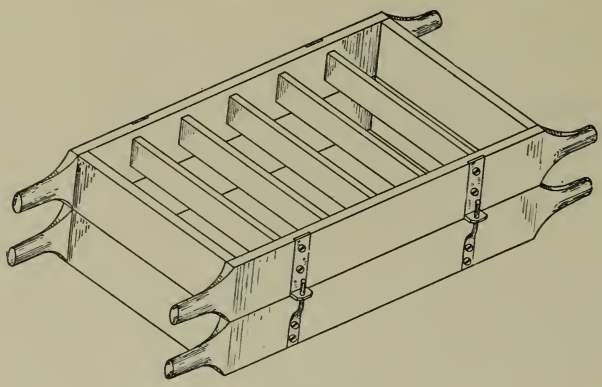


FIG. 36.

dry is well provided with flasks of various sizes, and for general purposes they are made rectangular, of wood or iron, and in two halves, as shown in Fig. 36. They have neither top nor bottom, but consists of rectangular frames with transverse ribs joining the opposite sides at equal distance along the length, to act as holding surfaces for the sand, and thus prevent the mass from breaking up. They must be open at the top and under sides, in order that the sand may be rammed in the flask. These ribs must be less in depth than the frame in order that there may be a depth of sand over the whole area for the reception of the pattern. The upper part is called the *cope,* while the lower half is called the *drag box;* the ribs in this latter are made much less in depth since this box is

not required to be moved around and inverted like the upper box. As the two parts must be removed and replaced in their exact positions they must be accurately fitted at all points of junction, and the sides and ends have pins on the drag box, fitting into corresponding holes in lugs on the cope. The two halves may be secured by hooks fitted into corresponding eyes, and before pouring, the upper box is also weighed with pig metal in order to prevent any movement in casting.

Materials Used in Moulding.—The material of the first importance is that of which the mould is to be constructed, and sand appears to be superior to all substances as satisfying better the following general requirements:

(1) The gases generated in the mould on pouring must be able to escape, at the same time the material must be compact enough to resist the pressure of the liquid metal, and prevent its exudation through the pores.

(2) It must bear the high temperatures and not be likely to set up any chemical combination with the molten metal.

(3) It must part from the casting easily, leaving the latter with a clean, clear, smooth surface.

Green Sand.—The principal constituents of this moulding sand are silica in a large proportion, for porosity, together with a small percentage of aluminum and magnesia for binding qualities. Care should be taken, in the sand employed, to avoid sand subject to what is known as "burning" when used, otherwise when wetted for use again it will stick and form a compact mass and ruin the casting.

Moulding sand is mixed damp with a percentage of coal or charcoal dust, in order to furnish a binding and porous material when the sand and clay are highly heated by the molten metal.

Core Sand.—For *cores* a mixture of abraded rock, or *rock sand,* and *sea sand* is employed, and after forming is baked.

Parting Sand.—This sand is used for sprinkling the joint, or point of separation in moulds of two or more sections. It consists of perfectly dry red brickdust, fine sand, blast-furnace cinder finely powdered, or fine dust from castings.

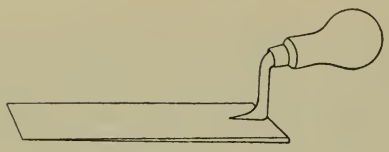


Fig. 37

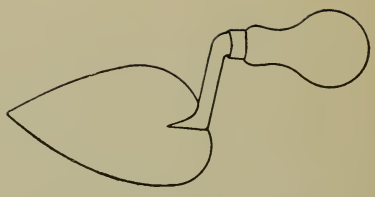


Fig. 38.

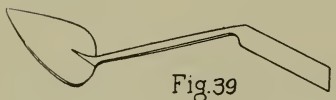


Fig. 39

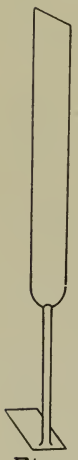


Fig. 47

Fig. 40

Fig. 41.

Fig. 42

Fig. 43.

Fig. 44

Fig. 45.

Fig. 46.

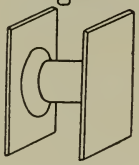


Fig. 48

Fig. 49.

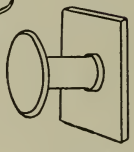


Fig. 50

Fig. 51

Fig. 52

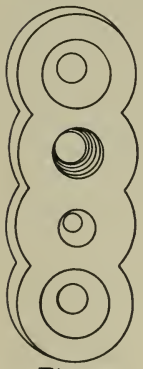


Fig. 53

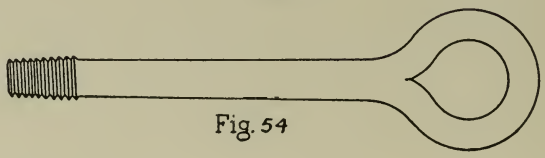


Fig. 54

Blacking—Black Wash, Mould Facing.—A carbon facing is spread upon the surface of moulds to resist the penetrating action of the molten metal on the sand, and at the same time to impart a smooth, fine skin to the surface of the casting. If the metal came into direct contact with the sand of the mould it would enter the minute interstices, with a resulting rough casting. These facings are generally some form of finely ground and bolted carbon, as oak charcoal, coal, graphite, etc. In the case of green sand moulding it is shaken evenly over the mould with a *blacking bag* and then smoothed over by returning the pattern, or with moulder's tools.

For *dry sand* and *loam* moulds and *dry sand cores,* the blacking is mixed with clay water to a suitable consistency, forms *blackwash,* and is applied to the mould with a brush.

Loam.—Following sand comes *loam* as a moulding material, and is a mixture of refractory fine sands with clay and some form of venting material added. The clay is added to give adhesiveness, while to counteract the want of porosity, any of the following materials may be added: Powdered coke, horse-manure, straw, chaff, hair, or chopped tow. The loam is mixed either in a loam mill or by hand.

Moulder's Tools.—In Figs. 37 to 54 are shown the principal tools employed by the moulder and consist of the following:

Trowels, heart-shaped, Fig. 38, and square, Fig. 37, for cleaning away and smoothing down the sand surfaces, and repairing injuries; *sleekers,* for smoothing and repairing sunken surfaces, are shown by Fig. 47; the flat portion is used for sleeking the sides, while the lower end is used for the bottom in sleeking or smoothing, and in removing the loose sand. Other sleekers for hollow moulding are shown by Figs. 40 to 46. Rammers are illustrated in Figs. 51 and 52.

Chaplets is the name given to the various devices for holding down or supporting cores, and to prevent them from floating out of position in the running metal. They must be free of rust, or tinned, on account of the evolution of gases when the rust is decomposed, and in addition they are an element of weakness. Chaplets are made of various shapes, depending upon the work to which they are applied, and in general consist of a stem with one end fitted with a flat or curved surface, as shown by Figs. 48 to 50.

In removing a pattern from the mould it is necessary to jar or loosen it; for small patterns this can be easily done by driving in a pointed rod and rapping it, but for larger patterns an iron plate, known as *rapping plate,* Fig. 53, is sunk even with the surface and secured with wood screws, and a lifting rod, Fig. 54, are employed.

In addition to the above tools, *shovels* are used for working the sand, *sieves* and *riddles* for sieving it, *bellows* for removing loose sand from the mould, *water pots* and *swabs* for applying water to parts of the mould, and *prickers,* consisting of long pieces of iron wire sharpened to a point at one end, for pricking the sand at various parts, to allow the air and gases to pass out during pouring.

Moulding.—Three different methods are employed in moulding, viz., *green sand, dry sand,* and *loam moulding.*

In both green and dry sand moulding, patterns are generally employed in forming the mould, the principal difference between the two methods is that in the latter the moulds, if in flasks, are dried in ovens, or if made in the floor are dried by improvised means, such as fires hung in pans or trays, while the sand used is generally a mixture of old loam and rock sand. Moulding in dry sand is more suitable for large and intricate castings; there is less risk of damage than in green sand; there is less likelihood of the sand sagging in parts, so that the moulds when dry may be placed in any position for casting, and less danger of corners, and pieces being carried away during the flow of the metal.

Loam Moulding.—This method of moulding differs from both green and dry sand moulding not only in the non-requirement of a pattern, but the mould itself is not contained in a flask, but constructed or built up in sections of rings, plates, and brickwork, the parts on which the mould is to be made being covered with soft loam, and swept up by a rotating or sliding template, called a *strickle* or *strike,* as for instance in moulding the core of a cylinder, Fig. 84. A cylinder of brickwork *J* is first built up on the plate *B* around the spindle *F,* the brickwork covered with loam, and the strike or loam board *G,* attached by arms to the spindle, is revolved, bringing the loam down to a smooth surface of the dimensions required.

Open-Sand Moulding.—The simplest form of green sand moulding is called *open-sand moulding,* in which the pattern is laid in sand on the foundry floor, or in an open mould, without a top. On withdrawing the pattern the metal is poured; no cover being used, the fluid metal assumes the horizontal position as in other liquids. Generally, however, closed moulds are used with top and bottom boxes, so that apertures for pouring the metal, called *gates,* are employed, together with other apertures for the escape of gases, and the air displaced by the entering metal. This method is frequently employed for common objects, such as moulding boxes, etc.

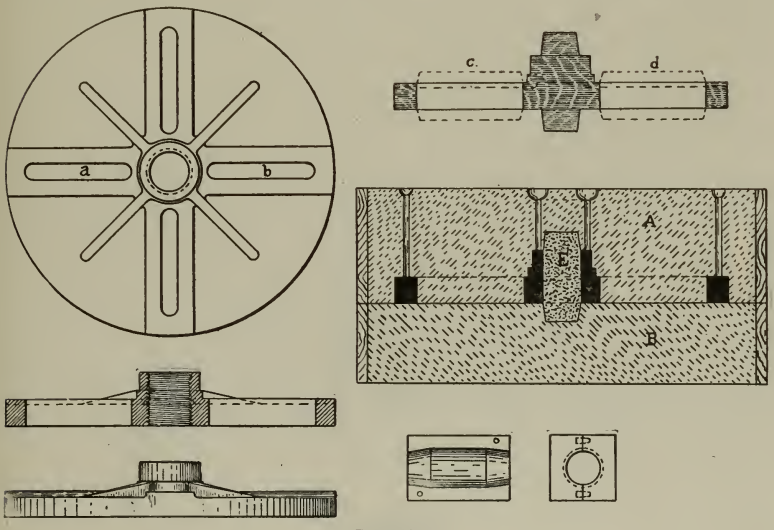


FIG. 55.

For a simple example of ordinary green sand moulding a large face-plate of a lathe may be taken, and will be explained in detail. In Fig. 55 is shown the ordinary drawing containing the *plan, vertical section,* and *elevation* of the plate. A pattern is made of the same shape as the finished casting, except at the center, where *core-prints* are placed for recesses in the moulds to support the *core.* A box of suitable size is selected to take the pattern, with a few inches to spare, so that it may be surrounded by sand. The pattern is now laid down on its face on a *follow* or *turn-over board,*

an ordinary flat board longer than the moulding box, and over this is placed the cope part *A* of the flask. A coating of facing sand, followed by fine moulding sand passed through a sieve, is thrown over the pattern, tapered wooden pins are inserted in the sand near the pattern, for the gates or passages for the liquid iron to the mould. Finally, common green sand passed through a riddle is added, and the whole rammed down with a flat rammer equally over all parts. This box is now filled, and rammed with the round flat rammer. The pins are now removed and the holes formed by them made bell-mouthed at the top, and smoothed to prevent loose sand being carried in. The cope is then turned over, using care to avoid any jarring that may loosen the sand. The lower surface of the box *A* and pattern are cleaned and smoothed, and as this surface is the parting, it is sprinkled with parting sand, and the drag or box *B* laid on it, guided by the guide pins, fastened down and filled with sand well rammed until it is flushed with the top. The drag or lower box is now removed from the cope and the pattern taken out, a slight rapping being given to the *loosening* or *rapping bar,* by which the pattern is lifted, in order to detach it from the sand, and then the edges lightly touched with a swab. In the operation of lifting the pattern, the mould is frequently broken at the edges and corners; these parts are replaced by the moulder, or the edges made anew with fresh sand. Next comes the application of the blackening, and to make it adhere, pease-meal is sprinkled over the mould, absorbing the dampness of the sand on the surface, and becoming a pasty layer. The blackening is now dusted over this part, the pattern replaced in position and pressed down, forming a smooth surface adhering well to the sand. The pattern removed, channels connecting the mould to the *gates* and *risers* are now made in the surface of the sand. A *riser* is a gate cut in the top or leading from the side of a casting and used either to indicate when the mould is filled, or a means of introducing fluid metal to make up for shrinkage.

The core is now set in place supported in position by the impression in the sand made by the core-prints, and the mould put in order for the pouring, the cope put on the drag box, fastened at the sides and ends by hooks and staples, well weighted down and *vented* by pricking the sand with *venting wires,* care being taken not to touch

the sides of the mould. The mould now being ready for the iron, the latter is taken from the cupola in ladles and pored simultaneously into the gates, and on its solidification the sand is broken up and a casting is obtained of the shape required, which is finished by machine tools to size called for by the drawings.

In this pattern no cores are made for the radial slots *a-b,* the pattern being open at these parts and made with sufficient draw, the green sand makes its own core. Had it been desired to use cores the pattern would have been made with core-prints, as shown at *c-d,* and cores of the proper shape being made to fit and inserted in the sand.

Making the Cores.—For the central core at *E,* a core-box, consisting of two blocks of wood, is gouged out and of the diameter required, and of a length equal to that of the core-print from end to end. Core-sand mixed with water to the proper consistency is placed in the core-box (which is pinned together), the holes of the box separated, the core smoothed, removed, placed in the core-oven to bake, treated with *blackwash,* and then inserted in place in the mould.

Long cores or those of complicated shape are stiffened and held in shape by iron wires and small rods, bent to the required shape and built up in the interior of the core while it is formed, and afterwards broken out of the casting along with the core. Venting the core is an important item and is done by piercing its length with wires or by strings laid along the stiffening wires and afterwards withdrawn, thus leaving venting passages.

Cores should be well baked, and are usually left in the drying oven about twelve hours, and to prevent them from absorbing water from the moulds, they should be placed in position only a short time before pouring.

Ramming.—This requires judgment and is dependent upon the bulk of the casting. If the sand is rammed too hard or close, the air and gases not escaping freely, the flow of the iron is irregular and uneven, producing excrescences in one part and corresponding depressions in another. When sand is rammed too loosely the weight of the iron bulges out the mould, producing irregularities and unevenness in the casting.

Gates.—The number of gates depends upon the surface area and thickness of the mould, a shallow moulding frequently requiring more than a deep one of the same area, the principal object being to run the metal in quickly and fill the mould.

The various gates and channels in moulding are distinguished by separate names; for instance, in Fig. 56, showing a rectangular block casting, the large gate into which the metal is poured is called the *pouring gate,* this terminates in a receptacle called the *skimming gate* and intercepts the dirt and scum. From the skimming gate channels are grooved into the sand to lead the metal to the mould called *sprues;* the *feeding gate* is used to fill up any part likely to shrink and keep up the supply, while the *riser* controls the passage of air out of the mould. A sound casting and the prevention of

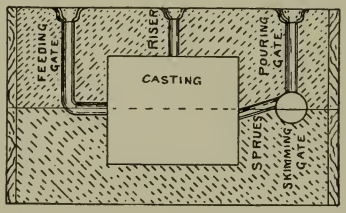


FIG. 56.

blow holes is obtained by properly regulating a covering placed over the riser.

Gates should be circular in cross-section, and rectangular shapes avoided; the size is governed by the flow of the metal, not too slowly so as to choke, nor so rapid as to break up the mould. During pouring the metal is agitated in the gates by means of a rod, and by this means a sound casting obtained.

Venting.—Moulds and cores contain proportions of organic and volatile matters, which when decomposed by the molten metal generate inflammable gases, while the steam from the damp sand is decomposed, giving out hydrogen and oxygen. The gases so produced, when mixed with atmospheric air, produce explosive compounds, and if ignited too soon are apt to produce disastrous results. There are various methods employed for venting these gases, from perforating the center of cores, and pricking the sand with

venting wires in the top and bottom of a flask, to the vent pipes in the complicated system of large high-grade castings.

The next example is that of a hand wheel for large stop-valves, the drawing of which is shown in Fig. 57, the core instead of being round is square, and the pattern in other respects is of the same shape as the drawing and, as in the preceding example, made in one piece. The procedure in moulding and casting is similar to that just described, except that the mould is contained in both the upper and lower box. The drag box is filled and rammed as before and the pattern *bedded-in*, that is, the upper face is cleared away with the trowel to receive the body of the pattern, which is laid in place and the sand tamped and smoothed down so that the parting is in

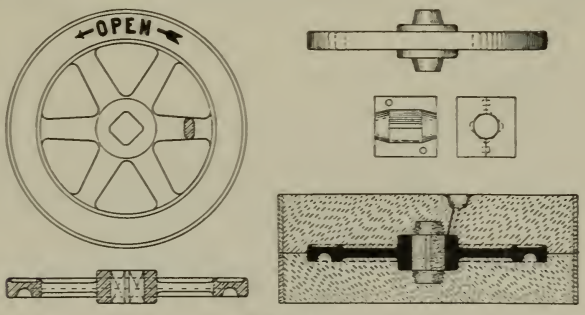


Fig. 57.

the middle of the rim thickness. The surface of the drag and pattern is now dusted with parting sand, the upper box put on and fastened, is filled with sand, tapered wooden pins located, and the sand rammed as before flush to the top and leveled off. The upper box is taken off, pattern removed, and the rest of the operation carried out as in the preceding example.

The next example shows some of the ingenuity which must be displayed by the moulder in handling work requiring special modes of management. An ordinary sheave has a grooved circumference, as shown in the drawing, Fig. 58, and the object is to draw the pattern without disturbing the ring of sand filling the groove of the sheave. The pattern is shown at *A*, with core-prints for the central hole, and must be formed in two halves, separated by a horizontal plane passing through the center of the groove. Referring to *B*,

the mould is prepared as follows: Bed the lower half of the pattern in the drag or lower box and form a parting *X-X* from the under rim to the edge of the box. The upper part of pattern is next put on and the ring of sand *CC* is rammed about the pattern, and a parting *X-Y* made from the upper rim to the edge of the box. Finally, the box is filled up and the sand rammed flush with the edge of the box.

The gates having been formed and the mould completed, the next operation is the removal of the pattern, which is done as follows: The upper box is lifted, the upper half of the pattern removed, and then the upper box replaced on top of the drag box; the whole box is now inverted, the drag box lifted, and the lower

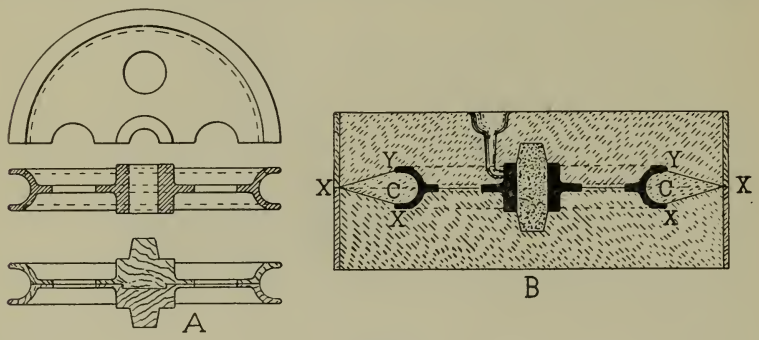


FIG. 58.

half of the pattern removed. The mould is now blackened and smoothed, the core put in place, and the whole box turned again, bringing the cope on top and the mould is ready for the casting. During this process the annular green sand core has not been disturbed, and is as firmly fixed in place as any other part of the sand mould.

The next example is that of a globe-valve, Figs. 59 to 65. To make the pattern, two blocks of wood of sufficient size for the length of the valve with its core-prints, and large enough to turn the globe or body of the valve chamber, are employed. As the pattern is to be parted in the center, the wood is faced true on corresponding sides, pegged together, and temporarily secured. Fasten the wooden block to the lathe, rough-turn it down to about one-quarter

inch of the finish size, scribe a center line around the body or globe, and mark off the checks for receiving the flanges at *A* and *B*, Fig. 60. In like manner check in the flanges of the piece intended for the branch and turn a tenon, *D*, on the bottom end. Disconnect

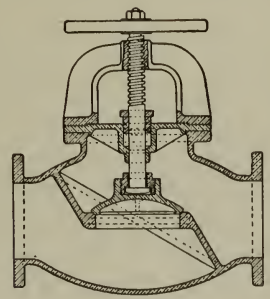


Fig. 59.

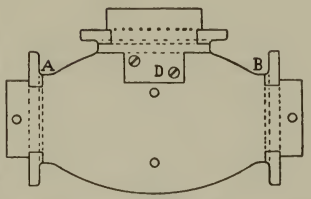


Fig. 60.

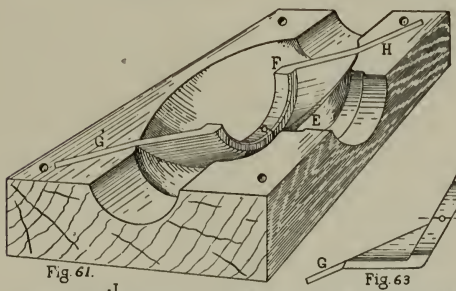


Fig. 61.

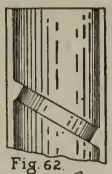


Fig. 62.

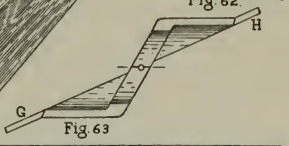


Fig. 63.

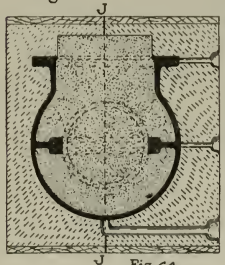


Fig. 64.

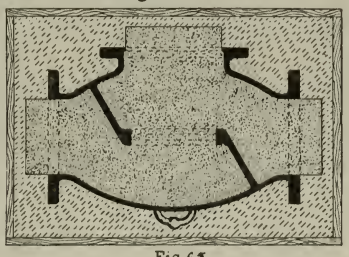


Fig. 65.

the two halves of the pattern, secure the flanges as explained in Chapter III, fasten together again the two halves of the pattern, which is then put in the lathe and turned to size.

The pattern is now removed from the lathe and re-chucked for the branch piece at right angles to the parting and parallel with

the center line of the body. The side of the body is then faced off, the recess made to receive the tenon, and the branch secured as shown.

The Core.—A view of half the core-box is given in Fig. 61, the opposite half being exactly similar except the reversal of the position of the internal partition *E*. In making this box take two pieces of wood of sufficient size to take in the inner diameter of the elliptical part and the length with the core-prints. Peg these pieces together and mark on the pegged surfaces the center of the body and center lines of the opening. Gouge out each half separately and cut the ends to the correct size, keeping the center of the body equally distant from each end, and then with the two halves together bore out the openings for the neck and branch. The diagonal bridges *E* are fitted in position in the bottom of each half and secured as a base on which to rest the curved partitions *F* and valve seat. Patterns are now made for these parts by taking two half pieces and turning them to the shape shown in Fig. 62. Cut each piece to shape, as in Fig. 63, and fit them into the recess in the core-box, on the diagonal bridge, and set down level with the joint surface of the half box.

Two strips, *G* and *H*, are fastened to the upper edges and to the core-box, level with the surface, in order to keep them in place. The pieces are then sawed in half with a fine saw. By this method the pattern of partition, and valve seat is in four pieces, and when the core has been made, and is ready to take out of the box, each piece is drawn separately, slightly turning it as it is lifted. Each half core is then turned over, the box lifted, and the separate half cores pasted together when dry.

When a number of valves are to be made from the same pattern the partitions should be of brass for durability and easier withdrawal. Also both halves of the core can be made from the half box by reversing the partitions.

Moulding.—First take a half pattern, laying the face down on a turn-over board, and over it in proper position, the bottom part of the flask; fill it with sand as previously described; turn over the flask with a parting at *JJ*, and put the upper half of the flask in place, set the gate and riser pins, fill with sand, and ram it in the usual manner, then lift the cope, cut runners, etc., insert the core,

replace and secure the cope, and after wire venting, the mould is ready to receive the metal, Figs. 64 and 65.

Moulding a Cylinder in Green Sand.—Steam cylinders are often complicated, made in a great variety of forms, and difficult to mould. They are usually swept up and moulded in loam, but for the smaller types, a pattern is employed and the mould made in green sand or dry sand. Taking the simplest example of a slide-valve cylinder, Figs. 66, 67, and 68 represent respectively the vertical section through the cylinder, a cross-section through the steam chest and exhaust port, and a cross-section through the steam port.

In making the pattern, the body is built up in staves similar to that in building a pipe pattern (page 71). The disc at the stuffing-box end, to which the staves are attached, is reinforced by an additional disc for turning out this end to the dished-shape shown, and lugs *A*-*A*-*A*, Figs. 67 and 68, for securing the cylinder to the columns, worked out and secured. At the opposite end of the cylinder an additional disc reinforcement is added equal in diameter to the cylinder *inside* the staves. The cylinder flange at this end is made in circular segments, glued up, turned to the size of the disc, slipped over it and secured, leaving a short portion of the disc projecting, which forms the cylinder core-print.

After turning the cylinder body to size, the steam chest is built and fitted to the contour of the cylinder body, Figs. 69 and 70, with pieces for the exhaust passage *B*, extra thickness for the steam ports and covering metal, core-prints for the steam and exhaust nozzles, piston-rod stuffing box core-print, the steam-chest core-print, and the valve-stem stuffing box core-print.

The pattern is parted horizontally through the centers of the steam chest and cylinder barrel to secure withdrawal from the sand.

Cores and Core-Boxes.—The barrel core *C*, Fig. 77, in this case is a dry sand core, made in a core-box with a longitudinal parting, the core-box is made of the inner rough diameter of the cylinder; the bottom end is made conical to agree with the shape of the inner side of the solid head, while attached to it is the core *D* for the piston rod stuffing box. A prolongation of the cylinder core projects beyond the flanges and fits into the recesses made by the pattern core-print and supports the core. A pipe is usually placed

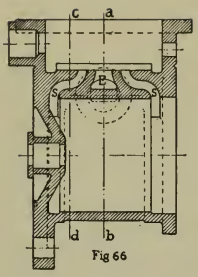
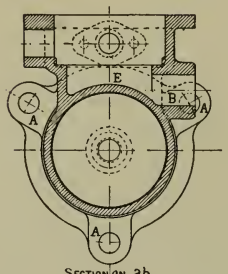
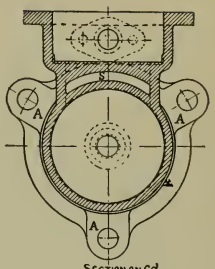


Fig 66



SECTION ON ab
Fig 67



SECTION ON Cd
Fig 68

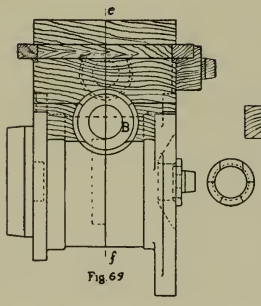
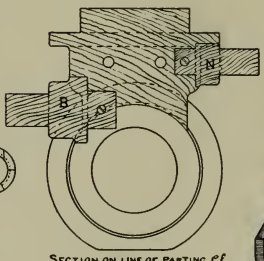


Fig 69



SECTION ON LINE OF PARTING ef
Fig 70

Fig 71

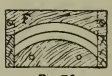


Fig 72

Fig 73.

Fig 74

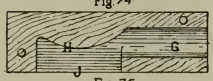
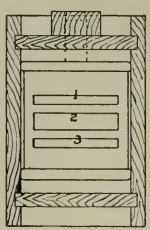


Fig 75



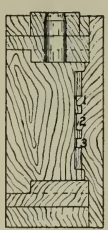
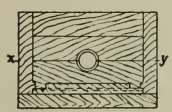


Fig 76.



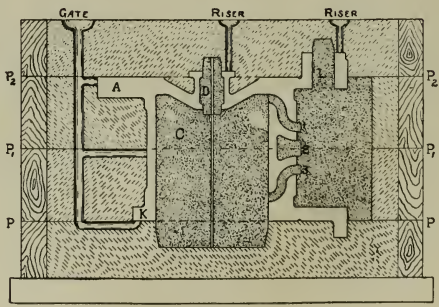


Fig 77

in the axis of the core-box and withdrawn after the core is completed, and thus serving as a vent.

In the formation of the cores which form the steam passages *S* and exhaust passage *E* from the steam chest to the cylinder, the former being alike can be made from one core-box, represented in longitudinal and end section in Figs. 71 and 72. These boxes are usually made open on the upper side to facilitate ramming the core, the material being shaped on this side by a template cut to the contour desired and drawn over the core, with the sides of the box as guides. Where the core changes from a straight to a curved part, as where it enters the steam chest and cylinder, these ends are sometimes covered, as shown at *F-F*, Fig. 71, and the sand rammed in. To preserve the shape in handling, wires bent to the required shape are imbedded in the core during the making.

The exhaust port-core and box is made in halves, Figs. 74 and 75, the cylindrical part *G* fitting into the recess made by the core-print on the exhaust nozzle. The curve *H* takes the contour of the cylinder, while the other side *J* enters into the valve-chest core. The two halves, after removal from the core-box, are pasted together after baking.

The valve-chest core and box is made, as seen in Fig. 76. The end of the box has a parting at *x-y* on account of the core of the valve stem stuffing box, while core-prints are fitted on the bottom plate, as seen at 1-2-3. The box is filled with core-sand and tamped, the upper half removed, the box turned over on a plate, the lower half of the box taken away, and the plate containing the core taken to the core-oven as before. When this core is inserted the steam and exhaust-port cores fit into the recesses 1-2-3, at the valve-chest end, while at their other ends, the steam-port cores fit directly on the large barrel core and fastened there by sprigs. For the exhaust-port core, its farther end passes into the corresponding print of the exhaust nozzle, made by the pattern.

The pattern having been prepared, the cores baked, the moulder proceeds to form the mould and assemble the parts. From an examination of the pattern complete with its cores, and the way it must be withdrawn from the sand, it will be seen that a flask of several sections is needed, in this case what is known as a *four-part*

flask, for if arranged for two parts, obstacles would be encountered in lifting the cope as follows:

1st, With the cylinder flange *K;* 2d, with the exhaust nozzle *B* and valve stem stuffing box *L;* 3d, with the lugs for cylinder column supports *A* and the conical cavity of the cylinder head, hence partings are made at *P, P_1,* and *P_2*.

The lug for the valve stem stuffing box, it will be noticed, can not be lifted so that it is made of what is known as a *loose piece,* a piece made separate and attached to the pattern with draw pins or dove-tailed, so that on withdrawing the pattern the loose piece is left in the sand and afterwards drawn out through the cavity left by the pattern.

Similarly, the lugs for the exhaust and steam ports, Figs. 69 and 70, can not be lifted without breaking the mould, but as they are on the parting, P_1-P_1, and in halves, each half is screwed to the pattern and after removing the upper half of the pattern on the line P_1-P_1, the half lugs *B, N,* can each be removed from the upper and lower pattern, thus permitting the lower parts of the flask to be removed.

Moulding.—The half section of the cylinder is bedded in the lower flask or floor, the flask filled in, rammed up around the main core-print and cylinder flange, and a parting made at *P-P.* The second flask is put in place and moulded up to P_1-P_1, when a parting is made. The other half of the pattern is now put in place, the third flask put on and moulded level with the top of the flange with a parting at P_2-P_2, and finally the cope put on and rammed up. The mould is now ready to be opened, the different sections of the pattern and loose pieces removed, and the mould finished up. When this is completed, set the cores, supporting them where necessary by chaplets, studs, anchors, etc., make the gates and risers, and secure the sections of the flask for pouring.

Fig. 77 shows a vertical section of the whole mould with all parts fitted to one another, the white space being that into which the metal is delivered.

The gates should enter the mould low down with its mouth higher than the top of the cylinder; by this means any scoria, air bubbles, dirt or retained gas is forced upward and escapes through the risers

or flow-off gates, thus insuring good solid metal in the working parts of the casting.

Cylinders may be cast vertically or horizontally, with green and dry sand; but with loam they are always cast vertically. Sounder castings are generally obtained from the vertical method, otherwise dirt and dross are likely to be caught under the main cylinder core and under the cope.

Dry-Sand Moulding.—Dry-sand moulding is extensively employed in the manufacture of the various water, gas, and air pipes, columns, and in general, bodies of the hollow cylindrical type, the firm and open consistence of dry sand by baking, making it well adapted for the above purposes. The duration of baking varies from a few hours up to several days, depending upon the class of work. The mechanical details in dry-sand moulding are very similar to those for green sand, patterns being used for the body, while the cores may be made either in dry sand or loam.

Loam Moulding.—In this branch the moulding is largely done without the aid of patterns, except those made by the loam itself, thus saving the cost of intricate and expensive wooden patterns. Loam working also renders possible the making of moulds, for which wood patterns could not be made. The various circular and cylindrical bodies, such as cylinders, cylindrical cores, etc., and also square or cubical vessels, may all be done in loam.

Large loam moulds are regular brick structures bedded in loam, and then covered on the striking side with a layer of the pasty loam. The material must be firm to sustain the pressure, and with sufficient porosity to permit the escape of the generated gases while pouring. The constituents of loam are clay and clean sharp sand, the former for the binding element, while the sand opens the grain. To this is added cow's hair, which increases the tenacity of the wet loam in moulding, and then in the after baking it is burnt out, thus increasing the porosity. Saw dust, horse hair, and straw may also be used.

For the different varieties of circular or cylindrical bodies struck from an axis, a central spindle is employed and set in the center of the part to be moulded; connected to this by two or more arms is a board or strike cut to the form of the object desired and set to the required radius. On rotating the *template, strike,* or *loam board,*

in contact with the soft loam, the figure of the body will be described. If the object is cylindrical and hollow, or cored, a strike is also provided to form the interior.

Pipe Moulding in Loam.—Fig. 78 shows a finished pipe main, with a bell-end (the larger end), and spigot-end, for connecting up successive sections. A pattern may be made for the outer figure of the pipe, and a loam core, or the whole may be struck up in loam. Taking this latter method, the core is first made and this piece must be rigid and porous, for any flexibility of the core varies the thickness of the casting, and the core being surrounded by the fluid metal must possess facilities for the escape of air and gases. Con-

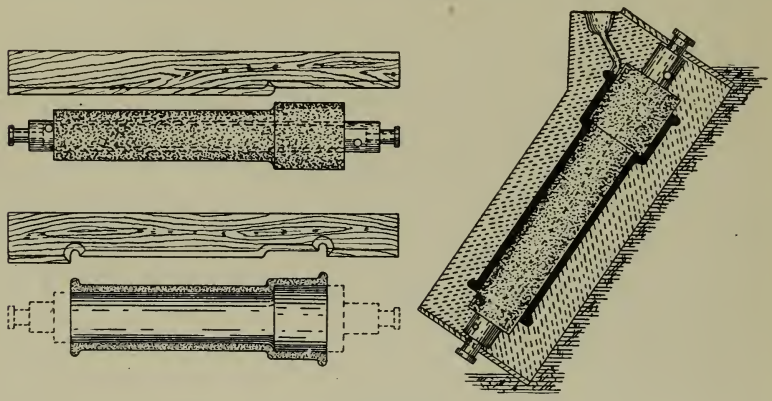


FIG. 78.

sequently a perforated gas pipe or tube is used for the center of the core, and with journals at its ends resting upon two trestles. The core center is made to revolve by means of a crank handle, and straw rope is tightly and regularly wound around along its length. A thin coating of loam is now applied to smooth down the surface, and when dried a second coating of loam is applied, and a loam board attached to the trestles at the correct radial distance from the center, and extending the length of the pipe. The edge of this loam board is cut to the exact form of the core, and as the core-pipe revolves, the loam takes the figure designed for the core. The core is then baked and blackwashed. The first board is now removed and a second one secured to the trestle at a distance to give

the required thickness, the core is covered with another layer of loam and struck up with the second loam board, thus forming a loam pattern. After this pattern is dried and blackwashed, it is placed in a flask and an impression made for the outer part of the pipe. The pattern is now removed, the loam last applied, broken, or cracked away, and the original core replaced in its proper position in the mould, gates made, flasks secured, and the casting performed as hitherto described.

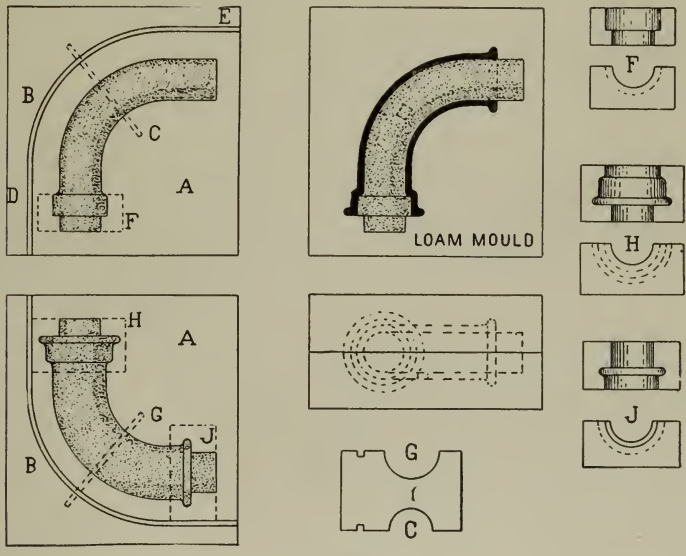


FIG. 79.

These pipe moulds are set either vertically, or in an inclined position, larger pipes being usually placed in a vertical position, so that in pouring, all the scum and slag collecting on the surface of the iron is brought to the top and clear of the casting.

Pipe Bends.—In pipe fitting, in addition to the straight pipe mentioned, bends, elbows, etc., are required in construction. If these fittings are required in quantity, it is usual to make patterns and core-boxes, in which case they are moulded in green sand in the manner similar to that already described.

When moulded in loam, a template, base plate, and guide are used as follows: A level iron plate *A*, Fig. 79, is first set in place.

on which is placed a square iron rod *B*, bent to the exact shape of the bend, for the purpose of guiding the template *C*, as it shapes the loam. A quantity of loam is laid upon the plate in the direction of the bend, the template, in moving over it, fashions it to the form of the inner surface, the template being guided by a notch fitting over the square iron guide. The length of the bend is fixed by careful measurements laid off from the ends *D* and *E*, care being taken to leave an extension at *E* to retain the core in place, while

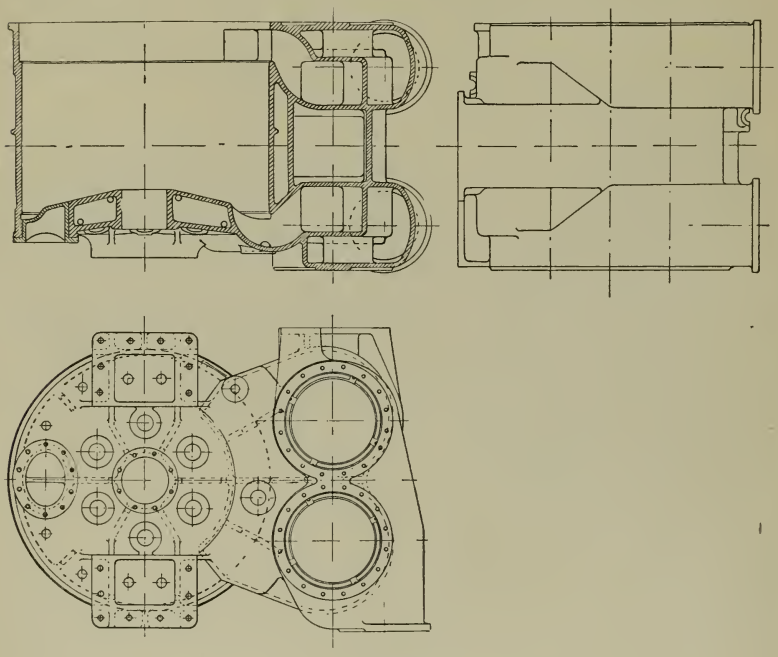


FIG. 80.

the bell-end is formed by a half core-box *F*. This furnishes one-half the core, which is then baked, blackwashed, and covered with a thickness of loam, then the larger template *G* used, and the mould swept up to the outside diameter of the pipe. The shape of the bell-end is given by a half core-box *H*, while the bead on the spigot-end is similarly formed by another half core-box *J*. Baking and blackwashing are again employed, and finally the whole plate and pattern is covered with loam, which must be well braced with

wires in both directions to prevent breakage in lifting. This loam block is now taken off, dried, and blackwashed, and an impression taken in sand. The loam thickness on the core cracked away, and the core cleaned up, the two cores pasted together, set in place, and the two parts of the mould put together in readiness for casting. Chaplets are usually placed at the bends to support the core.

Moulding a Cylinder in Loam.—The procedure in moulding a cylinder in loam varies in details to some little extent in different foundries, but the general operations are similar. The following details are largely compiled from an article by Captain G. H. Kearny, U. S. N., in the Journal of the American Society of Naval Engineers, Vol. IV. Of the sixteen cylinders cast for two U. S. Naval cruisers by this method, not one was lost.

In Fig. 80 the various sections of the L. P. cylinder are given from which it is seen that the cylinder is unjacketed except on the lower head, that the cylinder and steam chest are in one casting, and that steam is distributed by means of two piston valves.

From the dimensions on the drawings a foundation plate is cast in open sand of such size as to cover the projected area of cylinder end, valve chest, etc., and to allow for the building of an eight or twelve-inch wall around them. This plate has lugs and staples to lift and bind the mould together, openings through the plate for venting and securing the main core, and must have sufficient strength and rigidity to support the whole weight of the mould.

The foundation plate put in place and leveled, a steel spindle about three inches in diameter is placed in position, the foot fitting into a socket in the plate, the top secured by an arm from the foundry wall, and the vertical position of the spindle verified by a plumb line. A bracket or wing is then bolted to the spindle for carrying the different sweeps or strikes to be used.

The foundation plate is now covered with a layer of brick, over which is spread a layer of loam, and a bearing swept up for the *lifting ring*. Center lines are drawn at right angles on this seating, and the ends marked on the plate with a chisel, in case the lines become effaced.

Seatings to carry the valve chests are next laid out by means of the center line and a *gage stick*, this latter being notched in the center so that its center coincides with that of the spindle. Vent

pipes are laid in the bottom and the seatings built up with bricks to the proper height and covered with loam, the bricks laid in cinder for the escape of the gases. Attach the flange sweep to the wing, and sweep the main flange up to size, as given by the gage stick. A hollow *dummy* is next built and swept up to correspond to the circular part of the outer surface of the cylinder, from the flange to the top of the jacketed head, as in Fig. 81, showing dummy, valve chest seatings, *A*, and the foundation *B*, and lifting plates *C*. A light plate *D* is placed near the top to carry the bricks and loam which is swept to correspond with the outer surface of the solid head, the plate being slotted radially to enable it to pass the spindle. On completing the dummy transfer to it the center

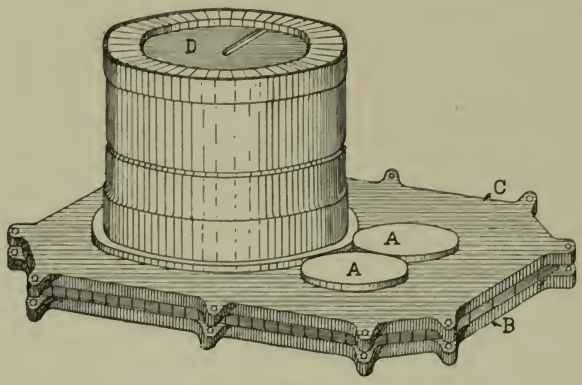


FIG. 81.

lines by means of the gage stick and a plumb-line. Care must be taken with the dimensions of this dummy, as all the patterns for steam chests, brackets, feet, etc., are set up to it.

Next cast the *lifting ring* or plate in open sand and of the shape and size to enclose the dummy, with all the projecting parts of the steam chest, etc., and fitted with lugs and staples for lifting and binding the parts together. The lifting ring is placed on the seating previously swept up for it, the lower part of the steam-chest pattern *E*, Fig. 82, placed on the valve-chest seating, and the loam and brickwork built up to it; after which the patterns for the rest of the steam-chest nozzles, exhaust passages, ribs, feet, brackets, etc., are laid up to the dummy, their position being determined by

the center line on the dummy. By the above operation an exact shape or pattern of the outer surface of the whole cylinder is produced. After oiling the surfaces of the dummy and wooden patterns to prevent loam sticking fast to them, the work of building up the mould proper is begun.

About one-half inch of loam is laid over the dummy and patterns and bricks laid up to it, this brickwork being about eight inches thick, except where necessary to support overhanging parts, when it is increased in thickness. Joints and interstices in the brickwork are filled with fine cinders, and at various points and corners straw is laid in order to make the mould porous.

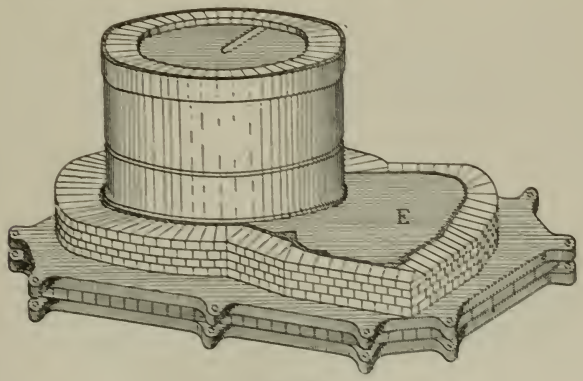


Fig. 82.

Where any narrow or weak points occur in the mould, these are strengthened by *gaggers* or *anchors*.

In building up a complicated mould it is necessary to divide it at parts into different sections or *draw-backs* to allow the pattern to be withdrawn and cores to be placed in position. These draw-backs are built on plates cast to the required shape, and a similar plate laid one course of brick from the top of the draw-back, the two plates secured when in position by hook bolts and staples, so as to form one solid mass. The seats for the draw-backs are made by covering the brickwork with loam finished for a parting. On the seating thus made is laid about one inch of loam, in which is bedded the draw-back plate, having prickers on the upper and lower side, the plate being clay-washed to make the loam adhere, then on

this lower plate the loam and brickwork for the draw-back is built up. These draw-back plates are bolted to the stiffening plates in the mould for strength while casting, and in building the mould are left to the last as partings must be prepared.

Cast iron stiffening rings are bedded in the mould as it is built up and the whole mass secured together by hook bolts to the lifting plate.

The main draw-back in the mould under consideration extends from the middle of the lower steam nozzle to the middle of the upper steam nozzle and from the line of the cylinder foot around to the other side of the cylinder, shown in broken lines, Fig. 83. Care

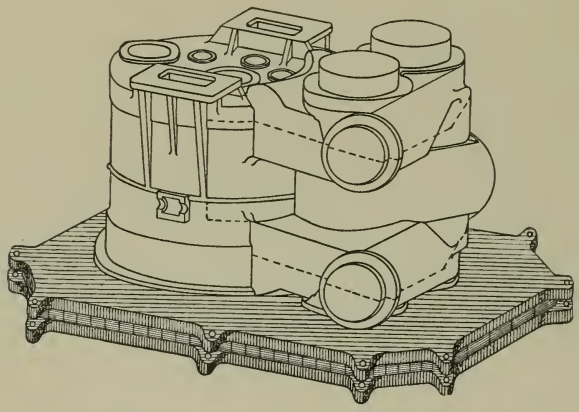


FIG. 83.

must be taken to leave openings where the steam and exhaust cores cut through the sides, in order to secure the cores in place and to insert vent pipes.

The outside of the mould having been finished, remove the spindle and cast a top or covering plate having openings in it for all parts of the mould that may project above it; these openings are for the top steam port, for cylinder feet or lugs, for securing and venting cores for steam jacket, piston rod, manhole, etc. These openings allow parts of the various patterns to be withdrawn and permit the moulder to dress and finish the mould, and are afterwards covered by smaller plates secured by hook bolts and staples to the top plate.

The top plate has prongs cast in the bottom side, and the plate is fitted in place to see that the prongs are of the right length, the ends conforming closely to the top surface of the dummy cylinder. Now invert the plate and wedge bricks tightly between the prongs, so that they will not fall out when the plate is again reversed; cover the bricks with a thin layer of loam, and dry the plate in the oven. On the removal of the plate from the oven, place it on the dummy and fit it by rubbing and scraping. This having been done, oil the top surface of the dummy and pattern to prevent loam adhesion, and cover it with a layer of loam, a clay wash having been put on the dry surface of the top loam to make the wet loam adhere to it.

The top plate now lowered on the wet loam and gently moved to and fro to make the loam take a good impression and to squeeze out any extra loam.

All joints where the mould is to be parted are sleeked smooth and marked to serve as guides in connecting up again. The top plate is now removed and the inside dummy next removed by picking out the bricks and dry mud, and, if the loam surface shows any irregularities, the spindle is put in place and the sweep used to correct it.

Next carefully remove the pattern for the steam chests, brackets, ribs, etc., either whole or in sections, lift away the draw-backs, withdraw the pattern for the lower part of the steam chest, and then replace and secure the draw-backs.

The foundry being supplied with cranes of sufficient capacity the lifting plate, with its mould, is lifted from the foundation plate and placed on a car convenient to the oven, and the uneven surfaces smoothed by filling up crevices or hollow parts with loam, the whole surface washed with fine loam, and the surface sleeked and black-washed with a brush.

On the removal of the lifting plate a covering of loose sand is placed over its seating to protect it, and the building of the main core, Fig. 84, commenced.

The spindle *F* is put in place with a sweep *G* attached at a radius to allow for shrinkage and boring the cylinder, and the main core built up with a double row of bricks, covered with loam, then swept up and the center part filled with loose bricks, with fine cinder be-

tween them, to prevent the danger of an explosion due to the accumulation of the hot gases mixed with air.

In the cylinders discussed the main core was made a little larger in diameter at the bottom than at the top, about $\frac{1}{8}$ inch, to allow for the pressure of the molten metal due to the height of the cylinder plus the riser. This precaution also helps to prevent the core from floating.

After verifying all dimensions of the main core, the spindle is removed, the core blackened and finished and removed to the oven. The mould should be dried slowly at first, to prevent too sudden expansion, increasing the temperature in about ten or twelve hours;

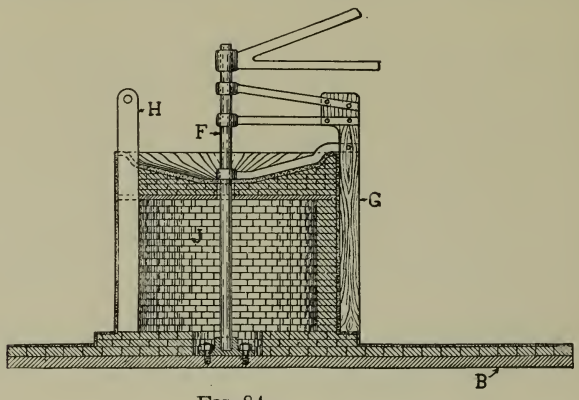


FIG. 84.

the complete drying taking from forty-eight to seventy hours, when the mould shows a light-brown color.

During the foregoing process, the dry sand cores are being prepared much after the fashion described in "Moulding a Cylinder from a Pattern," using wooden core-boxes of the requisite shape in making the steam chest and other cores. *Core-irons* are used for holding the sand together, they are made with prickers and cast to conform to the shape of the core. They are clay-washed before use, inserted in the sand, and the latter rammed all around it. The central part of the core is made of cinders for venting purposes.

In making the steam jacket core, the core-irons must be made very light as they have to be broken up and drawn out of small holes, after the cylinder is cast. In building up the main steam

chest cores, a wooden plug is built in the center, which, when withdrawn, leaves a clear vent into which all the port cores open by means of their cinder vents.

The foundation plate carrying the main core is now placed in a casting pit, dug in the foundry floor adjacent to the cranes, and cleaned up. The lifting plate carrying the rest of the mould is next lowered into place and the thickness space gaged by putting in rolls of putty or soft clay and taking impressions of the thickness. This being adjusted, draw backs are removed and cores for the steam chest nozzles and exhaust ports put in position, exercising care that the proper thickness of metal is allowed all round and that the cores match properly and in their exact place. Chaplets are used, as noted before, whenever they are required for support. As the cores are placed the draw backs are replaced in their proper position.

To secure the jacket core, tube bolts are used, tapped into the core-irons in the jacket core and secured to the top plate, and chaplets used to retain the correct space between core and top plate. The top plate also carries the manhole and piston rod stuffing box core, and when all are secured in position, the plate is lifted and the thickness ascertained by placing soft clay balls over the top surface of the main core and lowering in place again. This thickness space for the metal having been found correct, the clay balls are removed, chaplets inserted, and top plate replaced.

All joints and partings are now stopped up, tubes inserted in the cores, distance pieces placed between foundation and top plates, cross beams and stays secured around the mould, and all bound and clamped together.

A curbing of thin sheet iron is now built around the mould, leaving a space from eight to fifteen inches between mould and curbing; this is filled up with sand rammed hard, the curbing extending above the top surface of the casting, to act as a basin to pour the metal into and a runner to lead the metal to the gates.

The runners are now prepared by inserting *gate-sticks* in the openings that allow the metal to flow in the mould, and the vent openings completed by placing in them long tubes. Lumps of stiff clay with lifting hooks on them are placed over the risers and weighted down to keep a pressure of air in the mould while pouring.

Shavings and straw are placed in the vents and lighted just before the metal is poured in order to ignite the gas.

The temperature of the metal is important; if too hot, its penetrating power is too great and the mould injured; if too cool, the casting will show air or dirt holes. The metal should be taken hot from the cupola and when cool enough to just hang on a rod it should be poured.

In pouring the scum is skimmed off and the metal poured slowly at first; as the mould fills up, indicated by the air blowing through the gates and risers, the clay stoppers over the risers are lifted and the metal allowed to flow through.

When the metal in the runners becomes solidified, it is broken up and thrown to one side, the sand cleared away from the top plate, a way cleared down through the manhole, and a relieving bar *H*, Fig. 84, in the main core pulled out by the crane. This relieves the main core and avoids the danger of the cylinder cracking as the metal cools. The steam chest and nozzle cores are also relieved by partly breaking them up, while the curbing and its sand are removed, thus relieving the outer part of the mould and preventing interference in the shrinkage around feet, brackets, etc.

Sweeping up a Screw Propeller in Loam.—The principle of a screw propeller is that of a screw working in a nut, the water in which the screw acts forming the nut. The ordinary screw working in a metallic nut is a *true screw,* that is, as the spiral thread is wound around the axis, it advances along the axis at a uniform rate, but with screw propellers they are more frequently of varying or irregular pitch, either along the axis or from hub to periphery, the details and objects of which are treated in "Screw Propulsion" in the text-book, Naval Engines and Machinery.

It is evident from the definition of a screw, that if a strike or template be revolved about a central axis, at the same time be guided along the axis by an exterior guide, the surface swept up by the generatrix would be the helicoidal or working surface of a screw.

To illustrate the method of moulding, a true screw is employed, and the method of work with slight variation may be used for the different screws in general use. Taking, for example, a three-bladed screw to be cast entire, the following drawings are furnished:

A vertical elevation looking from aft, a side elevation, sections of the blade at various radii, showing the thickness, and the developed guide board.

In sweeping up a propeller there is required a *guide board,* which governs the *pitch,* and is used to direct the motion of the *sweep* or *strike* along the axis, and a central *spindle* placed at the axis of the screw, and to which the sweep is attached, free to move axially and around the center.

From the drawings there can be obtained the data for making the guide board for the sweep, and the thickness of the blade at different sections from the hub to the periphery.

The Guide.—This is shown in Fig. 86, and consists of a right triangle, built of wood and bent to the curvature of the radius at which it is to be set. For a screw of uniform pitch, the guide line *a-b* developed as a plane is a straight line.

The Sweep.—Wooden sweeps of various shapes are used, depending upon the form of the screw, and the parts to be moulded, and are secure to the spindle by the spindle arms or brackets.

The sweep, Fig. 89, between the hub and periphery is divided up by small notches on the working edge into as many parts as there are thickness pieces to be used. These notches leave a line on the swept face by means of which the thickness pieces are set; the sweep is balanced by a counterpoise, as shown in Fig. 90, in order to permit a free movement as it moves up and down the spindle.

Moulding.—A foundation plate of sufficient size is first cast, afterwards leveled in position, and the spindle set and secured. A layer of bricks is put on the plate and covered with loam about one-half inch thick and the sweep, Fig. 87, secured, with which sweep the seating is swept up with a small depression on the outer surface, on which the guide board sets. The center lines of the blades are laid off on the seating, and the hub built up of brickwork and loam, and shaped to form, by means of the sweep, Fig. 88, which is now attached to the spindle. After the hub is finished the hub sweep is removed, the sweep for the surface of the blade attached, Fig. 89, and preparation made for sweeping the blade surface. It is preferable to use two guide boards, one placed near the hub, in consequence of the sweep being cut away to clear the hub, it is liable to spring.

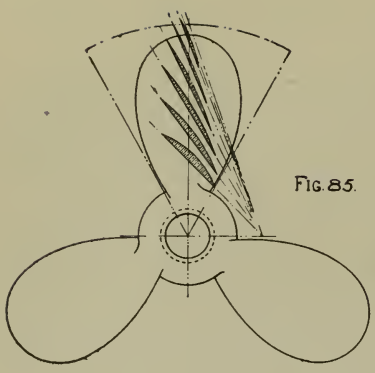
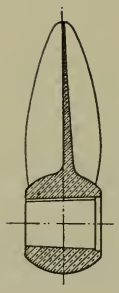


FIG. 85.



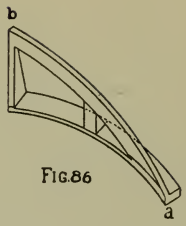


FIG. 86.

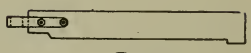


FIG. 87.

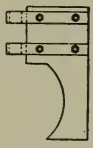


FIG. 88.

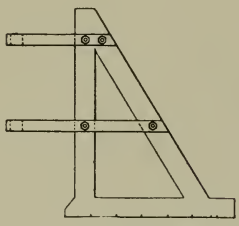


FIG. 89.

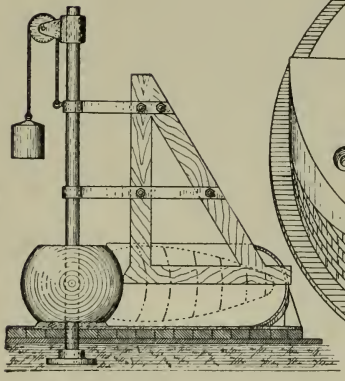


FIG. 90.

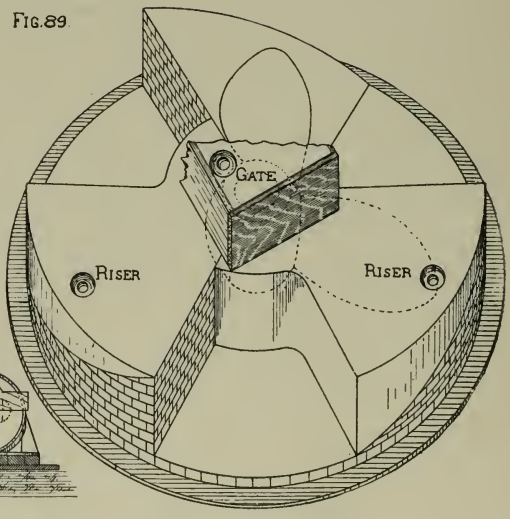


FIG. 91.

The guide boards having been placed, the piers are built up of brick and loam with straw or other material for porosity, the bricks covered with loam, and the sweep used to give the driving face of the blade. After this is swept up and sleeked smooth, the center line is transferred to it from the seatings and guide board, and the contour of the blade marked off. The thickness pieces of wood for the different radii are bent to the curves marked on the loam, then set in place and secured by nails. A layer of parting sand is placed over the swept-up surface of the blades, and the space between the thickness strips filled in with damp moulding sand, gently rammed and made smooth and fair with the tops of the strips, thus giving a copy of the back of the blade.

The cope is now prepared and consists of a number of flat plates bolted together, and made to correspond with the back surface of the blade. It is clay-washed to make the loam adhere to it, placed on the seating prepared, and clamped to the foundation plate, a layer of loam about three-fourths inch thick being laid over the image of the blade. Bricks are next bedded in loam and wedged tightly in the cope, and the joints covered over and marked to ensure the cope going back to its exact place. The cope is next removed, sand pattern broken up, and with the thickness strips taken away, the surface sleeked smooth, and vents, risers and gates provided for. The surfaces are then blackwashed and the moulds dried in the oven.

When sufficiently dried the parts are assembled, usually in a pit, hub core inserted, parts securely clamped together, and sand well rammed around it, in order that the mould may withstand the pressure resulting from the fluid metal.

After casting, the mould should not be opened too soon, and when opened the whole upper part should be uncovered at the same time, to secure uniform shrinkage and distortion of the pitch of the different blades.

The metal must not be too cool when run, or it will not fill out the thin edges of the blades.

In the half-tone, Fig. 92, the different stages in the operation are illustrated, the views being reproduced from photographs taken during the moulding and casting of several solid screw propellers, at the Norfolk Navy Yard.

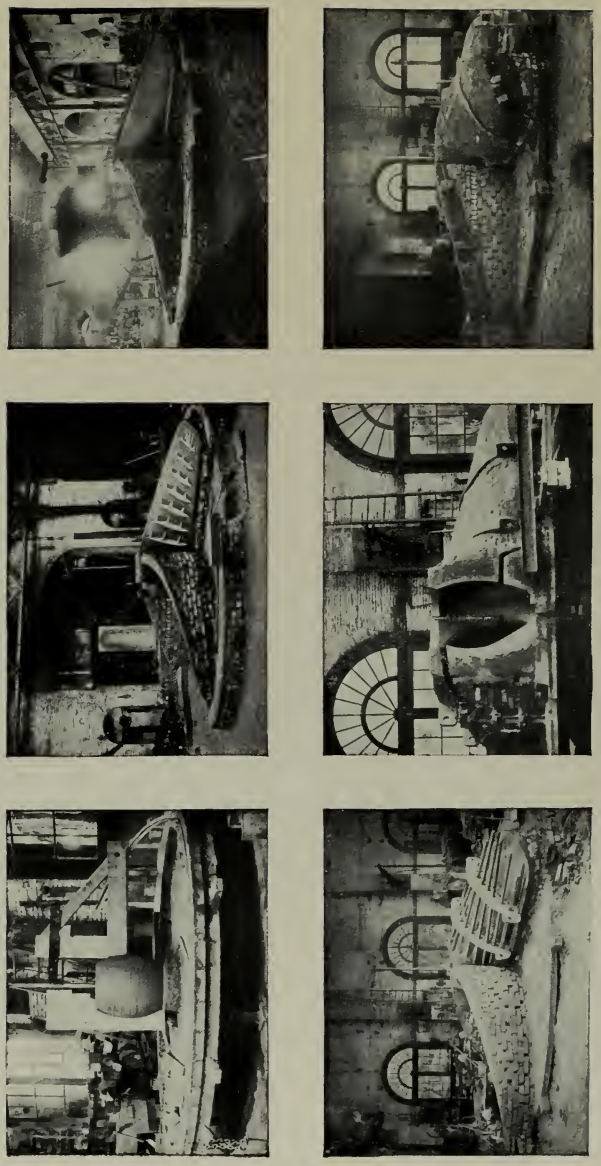


FIG. 92.

Chilled Castings.—When molten cast iron meets the surface of cold iron, the outer skin of the former cools rapidly and forms crystals of hard white iron, while the interior of the casting will remain of the same general nature of the pig from which it was cast, viz.: grey and soft. The chilling may be produced for an inch or more within the casting, depending upon the mixture used and the weight of the *chill mould*. The accepted theory of chill castings is that cast iron in a molten state is supposed to contain all its carbon in combination, and when this mass is suddenly cooled the metal solidifies, forming a substance similar to steel and called *white iron*, on account of its color and fracture. When a longer time is allowed for solidification, a more or less separation of graphite takes place with a consequent production of a cross-grained crystalline substance, called *grey iron*. On this assumption the sudden cooling of

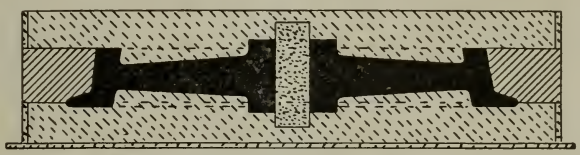


Fig. 93.

the metal at the outer portion, prevents the combined carbon at that part from separating, while the inner portion, cooling much more slowly, allows the metal to resume its normal condition; also that the carbon held in suspension near the outer part is forced inward, to the fluid portion of the casting. Hence a resulting hard-faced casting with a soft center or core. In chemical and physical properties the chilled metal closely resembles steel, but can not be *tempered*.

Of objects made in chilled castings there may be mentioned, the rims of car wheels when steel tires are not used, rolls for plate mills, projectiles, and other work where machining is not necessary, and a hard durable surface required.

The method employed in a chill casting is illustrated in Fig. 93. Three parts are used in the flask; the upper and lower boxes are of the ordinary form, filled with sand in the usual manner, and supports the central part and middle box. The middle box is of cast

iron, bored and finished, with its interior the exact reverse of the rim of the wheel. There is a great liability to breaking with chilled wheels owing to the difficulty in making the cast of a uniform strain, due to the expansion and contraction in cooling.

Improper cooling sets up severe internal strains, which are often great enough to destroy the castings, and on this account, soon after the pour has been made, the sand is knocked away and the red-hot (or incandescent) wheel is sent to the annealing oven.

Many articles, such as anvils, vises, etc., are made of cast iron with their working faces mounted with steel. Cast steel is used for the purpose, sheer and blistered steel not being adapted for the operation. Using an anvil for illustration, the steel face is made about five-eighths inch thick, ground on one side, covered with a coating of calcined borax, and heated until the borax melts and covers the finished side with a fusible glaze. The plate is then laid hot in a dry-sand mould of the anvil, and at the lowest part, and the iron poured in, rising from below, giving the steel face the hottest iron.

Malleable Iron Castings.—Malleability is obtained in white brittle castings by the process of decarbonization, or cementation process, by means of which brittle iron castings are converted into tough, soft, flexible material, resembling wrought iron.

In order to convert cast iron into malleable iron, the castings to be heated are packed into cast or wrought iron boxes, called *saggers,* along with red hematite or iron scales from rolling mill. The saggers are then placed in an annealing furnace and gradually heated to a red heat, which is maintained for the requisite time, after which they are allowed to anneal by slowly cooling down. The pig iron used should be the white or mottled, and not the softer grey. The time involved in the operation is to keep the chest at the maximum temperature from sixty to eighty hours, and the process of cooling for about thirty hours.

Malleable iron is in extensive use in the trades, many articles formerly requiring the forge are now made of malleable castings. It will take a polish, can be worked in a lathe similar to wrought iron, but the tools wear more rapidly; it has softness and flexibility but it is impossible to weld it, but it may be joined together by fusion and can be brazed to either wrought iron or steel by hard

solder. To an uncertain extent it can be hardened by heating to a red heat and plunging into water, and can be forged to a slight extent at a moderate red heat.

Case Hardening.—The term case hardening is applied to the process of converting the surface of iron objects into a form of steel, thereby obtaining the hardness of the latter with the comparative cheapness of the former. The operation is as follows: The objects to be hardened are finished up but not polished, then placed in iron boxes and between layers of animal carbon, such as hoofs, leather, or skins, etc., well burned and pulverized, and subjected to a red heat from half an hour to two hours, depending upon the depth of case hardening required. The articles are then removed and plunged into water. The method is similar to that employed in the cementation process of steel-making, the only difference from the cementation process being that the heat is only kept on long enough to steel the surface and not to carry the operation throughout the mass.

Cast iron may be hardened on the surface quickly by bringing it to a red heat and rolling it in a mixture of equal parts of powdered saltpetre, sal ammoniac, and prussiate of potash, after which immerse in a bath of water containing, per gallon, four ounces sal ammoniac and two ounces prussiate of potash.

Burning-on.—By this process cast iron may be brazed or mended by melting the joining edges and filling the space with molten metal. The usual method is to pour a constant stream of hot fluid metal along the fracture or on the surface until the parts are thoroughly fused, leaving an excess for subsequent turning and chipping. Burning-on is also practiced for fitting wrought iron structures with cast ornamental forms. Loam moulds are made and when dried are fitted to the wrought iron at the part desired; cast iron is then poured until the wrought iron is brought to a welding heat, when pouring is stopped, and when cooled, a firm attachment is found.

CHAPTER V.

STEEL CASTINGS.

Owing to the great improvements adopted in the method of manufacture, due to a better knowledge of the conditions, and which has resulted in the production of steel castings, which can be depended upon as being sound, the use of steel castings has grown to an enormous extent. Especially is their use in ship construction, in machinery details, and gun-mount constructions, a large and important matter. The size of the castings range from a few pounds up to some requiring as much as 350,000 pounds of metal for the pour. Much of the distrust and lack of confidence, of former years, in this material has disappeared, with the improvements in the method of manufacture and the quality and appearance of the castings.

The Manufacture of the Steel.—Steel scrap, pig iron, and iron ore are the raw materials employed. Naturally the selection of the stock and the manipulation of it in the furnace are of great importance. The scrap consists of the ends of plates, shapes and forgings, and turnings from the machine shop. The bulk of a furnace charge is scrap, the proportion of pig being about one-fifth, where a furnace is newly lined, and increasing to three-tenths when the furnace lining is well slagged and nearly burnt out. The amount of iron in the ore is a secondary consideration, the ore being used principally for its oxygen, and used in oxidizing the metalloids, carbon, silicon, sulphur, and phosphorus. The proportion of ore required depends upon the character of the other ingredients; in an acid furnace from one to two and one-half percent, although there are cases where scrap could not be procured and from necessity the charge was made of pig and ore, over three-fifths being pig. Hematite ore is the variety most used and is obtained in the Lake Superior region, or imported from Canada, Cuba, Spain, and elsewhere.

Composition of the Raw Material.—The exact constitution is

determined in the laboratory, and the definite proportions in the charge fixed, according to the character of the steel desired. The amount of carbon combined with the iron makes one difference between wrought iron, steel and cast iron. Another difference is the method of manufacture, with the resulting properties and character. Wrought iron is soft and fibrous, cast iron is hard, crystalline and brittle; steel comes anywhere between. About three heats can be run per twenty-four hours per furnace, depending upon the size of the furnace and character and quantity of work.

The Furnace.—The raw materials are melted down in a reverberatory furnace, with gaseous fuel distilled from bituminous coal in gas producers. Under each end of the furnace is a pair of regenerators, one for air and one for the gas, as in the case of the open-hearth furnace used in steel manufacture, and is the same furnace already described. The furnace process will be acid or basic, according to its lining, basic lining and additions being used in one case, and an acid lining, such as fire-brick or fire-clay, in the other. Basic steel is not so generally used for castings as that of the acid product, but cheaper raw materials can be used in the basic process, and the objectionable element, phosphorus, can be nearly eliminated. It is more expensive than acid steel, on account of the greater waste, diminished output, and fewer runs of the furnace can be made.

Towards the end of the melt a small quantity is taken out in a ladle and a test ingot cast and rapidly cooled, broken in two, and the character of the bath approximately determined by the appearance and color of the fracture, and then a rapid chemical analysis of the drillings from the test ingot made. If the bath is right, or made so by decarburizing with scrap, as shown by the last of the test ingots, the bath is re-carburized with calculated amounts of ferro-silicon and ferro-manganese which effect the final reduction of the oxides of iron, and brings up the percentages of carbon, manganese, and silicon to the points required by the specifications, to give the necessary physical properties.

The whole mass of molten metal after this introduction becomes quiet, and the ladle is then swung around under the tap hole, and the metal run out, carried to the moulding floor, and run into the moulds.

A sample analysis is given from two runs:

Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.
.332	.339	.696	.0414	.049
.282	.294	.647	.042	.0508

The first set was to meet specifications from the Bureau of Steam Engineering calling for an ultimate tensile strength of 70,000 pounds per square inch, 10 percent elongation in eight inches, and a reduction in area at the point of fracture of at least 20 percent. The second was from castings which had to show 60,000 pounds tensile strength, 15 percent elongation, and a reduction of 20 percent.

The physical qualities of the castings depend upon the chemical constituents, the strength increasing with the carbon but the ductility decreases, and steel very high in carbon has little extension.

Manganese.—In steel-making, manganese facilitates the combination of carbon with iron, increases fluidity, prevents ebullition during solidification, and the formation of blow-holes, increase tensile strength, and counteracts the evils produced by the presence of copper, silicon, and phosphorus.

Silicon increases the fusibility and fluidity, lessons the formation of blow-holes, and is said to harden or render the metal more brittle but prevents to some extent red-shortness.

Phosphorus.—The presence of this substance in steel castings to any appreciable amount is very objectionable, and causes the steel to be very untrustworthy, especially when subjected to sudden shocks. It appears to collect in spots and the proportions in different parts of a casting will vary. Produces "cold-shortness" and liability to cracks.

Sulphur.—The amount of sulphur in steel castings is of little importance, as it effects the cold properties very slightly, and no harm is done by specifying up to .05 percent, good castings generally containing less, and there is no evidence that it has any effect upon the finished casting. In steel forgings, sulphur would interfere with working the metal, causing "hot-shortness."

Aluminum, in small quantities, is believed to have the same effect as regards blow-holes, as silicon and manganese, but without any of the evils of those substances, the pour becomes more fluid. Aluminum is used particularly in heats for light castings.

Moulding and Casting.—Moulding for steel is similar to that for cast iron, but requiring the best skill and the highest workmanship to successfully cast the intricate forms now used in structural work. The principal difference in iron and steel moulding is due to the higher melting point of the latter, its rapid solidification, the great shrinkage and the gases developed in cooling. The body of the mould is made of moulding sand, packed a little harder than for iron, with a facing of fine ground quartz. Back of the sand, next to the pattern, cinders are filled in for venting and the yielding of the mould when the metal is solidifying and shrinking. The mould is also freely pierced with venting rods, and vents opened to the cores through the core-prints. The surfaces of the mould are finished off with a wash of silica, molasses and water, applied with a swab. The flasks are of cast iron or steel.

Feeding Heads.—To give a ferro-static head to the molten metal and to feed the casting as it cools and shrinks, *feeding heads, sinking heads* or *risers* are employed. Steel chills so quickly that it can not be fed like cast iron from small heads, so that risers, larger in sectional area and higher, are employed to contain plenty of metal to remain liquid longer than the casting, thus in addition to feeding they maintain a ferro-static pressure on the body and fill all parts of the mould.

Drying the Mould.—The mould and cores are thoroughly and slowly dried in ovens. The thorough baking of the mould and cores is a necessity, as any moisture present is almost certain to spoil the casting.

During the moulding operations and while the charge is melting down in the furnace, the heavy ladles are swung in place and their linings thoroughly heated by oil burners. The furnace is next tapped and the metal run into the ladle, which is transported by a travelling crane to the moulds, and the metal poured. Small crucibles are also carried to the moulds to make good any small deficiencies in the runners and risers, due to cooling and shrinkage, while the mass of the metal is still fluid. The shrinkage of the steel is now accommodated by the yielding of the mould and at the same time any steam and gases generated must find vent through the mass of the sand and cinder.

Annealing.—After a suitable time, dependent upon the size and

weight of the casting, the flasks are knocked apart and the casting cleaned and removed to the annealing furnace, where it is gradually and uniformly heated up to a temperature varying between 1200° and 1600° F., kept soaking at the maximum temperature according to the size of the piece, then gradually cooled without exposure to the air. Annealing improves the metal by rendering the texture more uniform and removing internal strains. When cold, the coupons are detached, test specimens cut out and machined, and tested in accordance with U. S. Naval Specifications governing the inspection of "Steel Material," Appendix G, Naval Engines and Machinery.

Shaking Out.—The weight and proportions of a casting govern the time it is kept in the sand. Some light castings may be *shaken out* soon after pouring, while large castings are often permitted to remain in the sand for several days.

Precautions to be Observed.

1st. The mould must be thoroughly vented and the metal so poured as to carry in little or no air, for, as soon as the mould is filled, the metal at once chills around the surfaces, and "freezes in" the air bubbles or gases given off in cooling; these would naturally rise to the surface, hence the necessity of large risers.

2d. If the runner is not well baked and the sand packed, the flow of metal cuts it out and carries the impurities to the mould.

3d. The moulds and cores should be sufficiently strong to carry the ferro-static head, but frail enough to crush during contraction, while of a sufficiently open nature to permit of a ready escape of gases and vapors.

4th. The shrinkage amounts to from one-eighth to three-sixteenths of an inch to the foot, and is one of the most difficult problems to deal with. Careful attention to this question should be given in the design. All angles should be well filleted, sudden changes of shape avoided, and large masses of metal should merge gradually into the thinner parts.

5th. As the metal sets almost immediately on entering the mould, the importance of having the mould hot at the time of pouring will be readily understood.

Defects.—As the fluid mass cools, small bubbles of gas are squeezed out by the shrinkage of the metal in which they have been held in solution, and gather in the mass of the casting just below the surface, forming tubular cavities called *blow-holes.* Silicon prolongs fluidity and permits these gas bubbles to float towards the surface or risers.

Sponginess.—If the mould is not well baked or is damp, steam is generated on the contact of the hot metal, and passing through the mould will make it porous, producing a *spongy* condition in the casting.

Shrinkage Cracks.—If the mould is rammed too hard, it will not yield readily to the shrinkage of the casting, the latter will tear apart at the weakest or thinnest places, or where surfaces change direction producing *shrinkage cracks.*

Scabs.—Produced by injuries to the face of the mould, due to breaks or washing of the mould by the entering metal.

Brittleness.—Due to an excess of phosphorus, or to crystallization of the material in cooling.

Cavities.—Recesses formed in the heavy part of a casting, due to shrinkage, and generally to defective design or faulty moulding, as in poor arrangement of the risers.

Uses of Steel Castings.—In naval machinery, hull fittings and construction, the uses of steel castings are many and varied. They are used for cylinder and valve-chest covers, pistons, cross-head guides and slippers, bearing caps or covers, eccentric sheaves and straps, rocker arms, thrust-bearing boxes, bed plates and housings, and other parts of the main and auxiliary machinery; for manifolds, manhole and hand-hole doors, and for various boiler fittings, anchor davits, hawse pipes, chocks, mooring and towing bitts, stems, stern posts, stern tubes, manhole covers, and other parts of the hull fittings, together with the gun-mounts and parts of the electric generators and motors.

Brass Founding.—Moulding for casting in brass is very similar to that for cast iron, in all the details of pattern-making, moulding, gates, runners, etc. The principal difference in the operation being the method of melting the metal, crucible furnaces being used for small and moderate size work, and reverberatory furnaces for large castings, such as are used in marine engine work.

A *crucible furnace* is represented in Fig. 6. Usually several of them are placed in a row and separately connected by flues to the smoke-pipe, so that one or more may be employed without interfering with the draught. These furnaces are usually sunk below the foundry floor, and their interior is lined with a refractory material, usually fire-bricks set in fire-clay. The top of the furnace is covered with a movable cover made of wrought or cast iron, while there should be a damper connected to the flue.

The *crucibles* employed should have the characteristics of impermeability, should not corrode, and be capable of withstanding

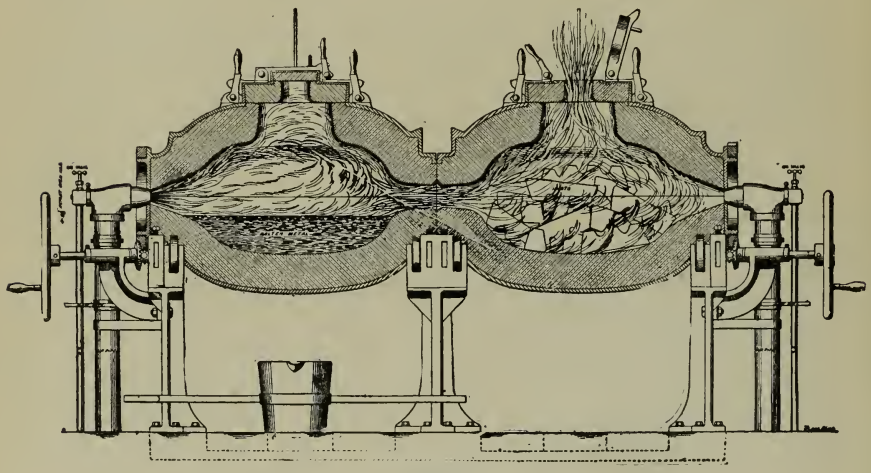


FIG. 94.

sudden changes of temperature; black lead fulfills these conditions better than other materials.

In making brass, care should be exercised in the mixing as the melting-points of the constituents vary largely; for instance, copper melts at 1990° F., while the melting-point of zinc is 770° F. The least volatile metal should be melted first, the others being introduced in small lumps just before pouring, and plunged down under the molten metal with tongs.

Operation.—For fuel, hard coke is used broken into small lumps. The crucible is first heated thoroughly, then bedded on a fire-brick slab and the fire banked around it, the metal introduced, and the

crucible covered with its top. The mouth of the furnace is then covered, and the damper opened. In introducing the metal the copper is first melted, then the tin, and the fluid metal tested with a few pieces of zinc. If the zinc flares up, it is an indication that the heat is quick enough, and the balance of the zinc should be thrown in. If the heat is continuous beyond this, the zinc will be lost by evaporation. The crucible is lifted from the furnace by *crucible tongs,* the dirt and dross skimmed from the surface, and the metal poured.

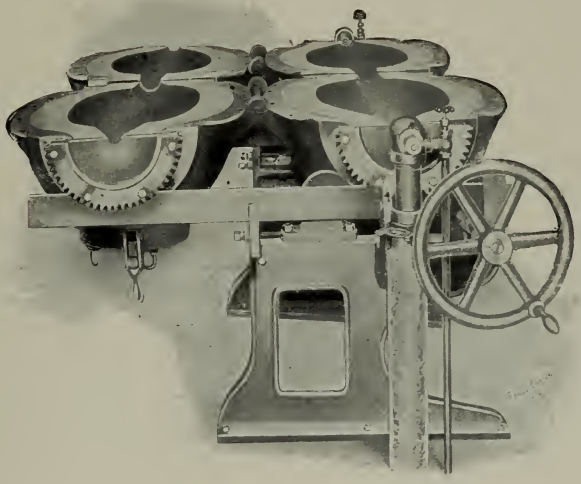


Fig. 95.

Volatilization of the zinc may be prevented, to some extent, by spreading charcoal over the metal while being melted.

Rotary-Melting Furnaces.—Another method of brass melting now much in general use, is the rotary brass-melting furnace, in which fuel oil, or gas fuel, is used, and the use of crucibles with their expense and care is dispensed with. The operation of this plant can be seen in the foundry of the Engineering Building.

Referring to Fig. 94, the apparatus consists of two double chambers communicating with each other; while the metal is being melted in one chamber, the charge in the other is receiving a preliminary heating at quite a saving in time and fuel. One chamber

can be pouring while the other is melting, or both can be poured simultaneously. There is an oil burner at each end, and when both chambers are charged with metal, only one burner is operated at a time, the firing and melting occurring alternately from right to left and left to right, while the spent gases escape from the live or primary chamber through the neck into the secondary chamber, where another absorption takes place, and then finally discharged into the open air under a hood. At intervals the current is reversed, the secondary chamber becoming the live chamber and vice versa.

The chambers are of steel, divided longitudinally through their axis, hinged on one side, and bolted through their flanges as shown. In the center of each chamber is a port for charging the metal, and fitted with a hinged tight-fitting steel cover held by clamps. The chambers are mounted horizontally on rollers, and fitted with worm gears and hand wheels, for the purpose of revolving and pouring.

The burners at the end are fixed in position, fitted with valves, and can be easily removed when desired. The chambers are lined with a refractory material, rammed in around a lining form, similarly to sand around a pattern in moulding, and after removing the form the lining is burned in place. In Fig. 95 is shown an end-view of the furnace, ready to close after re-lining. In Fig. 96 is shown the entire plant, similar to that installed in the foundry, and from which the complete operation can be seen. The fuel oil tank is imbedded in the ground outside the building, the oil being taken by the oil pump and sent to the burner, while the blower with the air discharge pipe carries the air under necessary pressure to the same point.

Brazing—Soldering.—Soldering in general is the operation of uniting the surfaces or edges of metals and alloys by partial fusion at the joint. The solders used are more fusible than the metals to be joined, and when placed between them and heated the solder melts and unites the parts into a solid mass. It is important that any metallic oxides or impurities be removed from the surfaces before the application of the solder and heat. To prevent any oxidation during heating the parts are also covered with a flux, which protects them from the action of the air, and tends to reduce any oxide existing.

Under the term of soldering two methods are employed, *hard*

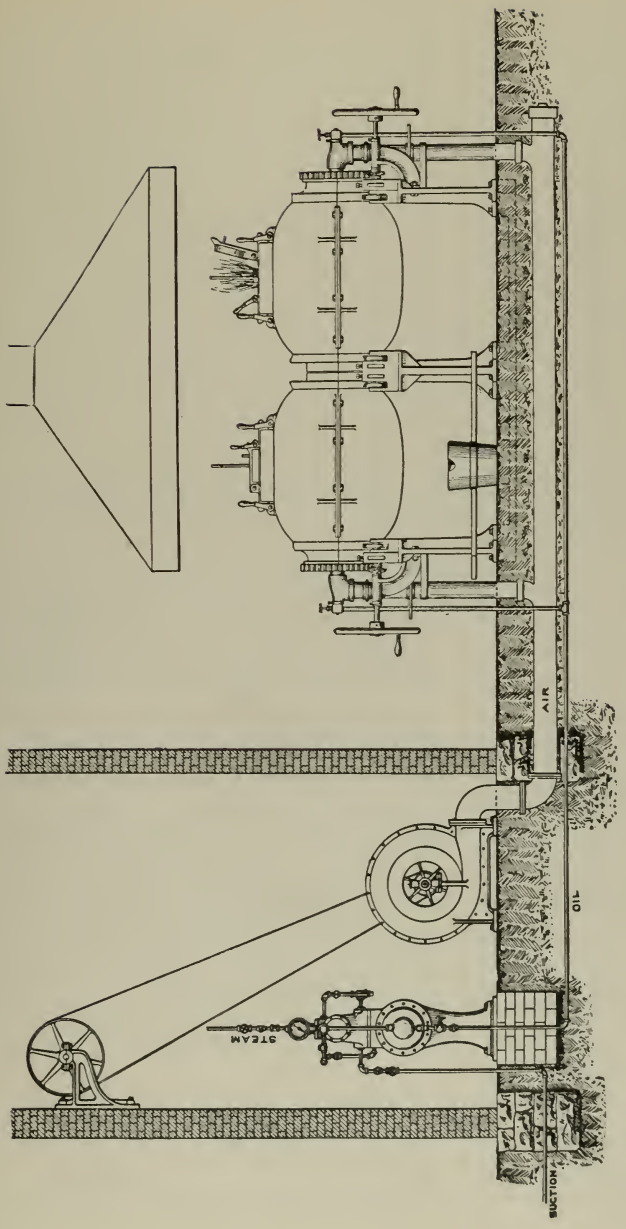


FIG. 96.

soldering or *brazing* and *soft soldering;* the solder used in the former fuses at a red heat, and is used only for metals and alloys that will stand that temperature, while the soft solders melt at very low temperatures and may be used for nearly all metals. In brazing it is often necessary to bind the parts together with binding wire in their proper position before applying the solder and heat. In soft soldering, binding wire is seldom employed, as in the local application of the heat with appropriate tools the work can be easily manipulated by the hands to retain it in proper position.

Brazing or Hard Soldering.—The solders most commonly used in brazing are *spelter* solder and silver solder, and the flux generally used is borax. Spelter is made of equal parts of copper and zinc, melted, poured into a mould, and then broken into small lumps, which are heated to redness upon a charcoal fire, then broken up quickly on an anvil or in a mortar into a fine granulated form.

A charcoal fire is best for brazing and the heat is taken on the brazier's hearth or the ordinary blacksmith's forge, while in many cases of very delicate and small work, requiring deft manipulation, the blow-pipe is used. In brazing or soldering in general the edges to be united are filled or scraped as previously mentioned, the joints of the material to be worked upon (copper, iron, brass, etc.), are secured in position by binding wires, the granulated spelter and powdered borax are mixed together with a little water and spread along the joint. The work is now placed above the clear fire and the borax boils up in a froth. With the increase of heat the metal becomes a faint red, the borax fuses quietly, and at a bright red the spelter fuses, showing a blue flame, due to the ignition of the zinc. By tapping the pieces lightly the fused spelter runs into the joint, the piece is then removed from the fire, and as soon as the spelter has set, the parts can be quenched in water. During the process of heating, the piece should be moved about to distribute the heat as uniformly as possible, and thus avoid burning or melting the metal as well as the spelter.

With silver brazing or soldering the process is very similar. The solder varies according to the work required, and is usually for general work, three parts fine silver and one part of brass wire. The joint is first given a coating of borax and water, the solder laid on

in small strips, and especial care is taken in heating not to displace the solder. Mathematical and drawing instruments, jewelry, etc., are soldered with silver, and in this case a blow-pipe is used.

Soft Soldering.—The solder used is a composition of tin and lead in different proportions; plumbers' solder for lead pipe usually consists of two parts of lead and one of tin, while for tin plates and ordinary solder, the composition is about two parts of tin and one of lead. As in hard soldering, the joints to be soldered should be clean and free from metallic oxides. For light work on sheet tin, zinc, copper, and other thin metals *soldering irons* are employed to convey the heat to the parts being worked. A sketch of the soldering iron is shown in Fig. 97, and consists of a pointed piece of copper weighing from several ounces to five pounds, riveted into iron

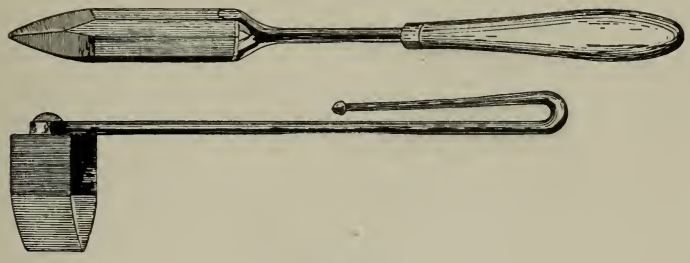


Fig. 97.

shanks, and fitted to wooden handles. The copper end should be tinned by heating to a dull red, quickly filed clean, and then rubbed first upon a little sal ammoniac, then upon the solder until the tool is coated, and then wiped clean. Another type of soldering iron for heavier work is shown in the same figure.

For soldering sheets of tin, the joints are slightly coated with powdered resin or brushed with chloride of zinc (hydrochloric acid in which are placed thin strips of zinc), then a few drops of solder are melted off the solder stick, at short intervals, and the soldering tool run along the joint, both to fuse and distribute the solder. Use care in heating the tool; if too hot, the solder is made too fluid and difficulty will be experienced in picking up the small drops of solder and brushing them along the joint. Sal ammoniac is also frequently used as a flux in soft soldering.

For heavier work the soldering iron is not applicable as the amount of heat required to be given to the metals to be joined in order to raise them to the melting-point of the solder cannot practically be given in this manner. In this case the two parts are first tinned, then heated with a little additional solder, until the latter is fluid, the two surfaces rubbed together to spread the solder uniformly, and the piece is then allowed to cool under pressure.

CHAPTER VI.

THE FORGE.

The equipment of a modern plant depends upon the character and size of the work required. For a marine engine plant the requirements for the purpose would be the following, in quantity proportionate to the extent of work and number of hands employed:

1. Heating furnace for heavy work.
2. Smith's forges or hearths.
3. Anvils.
4. Blower and exhauster.
5. Annealing furnace.
6. Hand and power cranes.
7. Steam hammer.
8. Bending blocks.
9. Vise benches.

Of the necessary forge tools the following may be mentioned:

Hammers, hand and sledge.
Set hammers.
Cold chisels, hot chisels.
Hardies.
Fullers.
Flatters.
Punches.
Bolt-heading tools.
Swages.
Swage block.
Tongs, flat nose.
Tongs, round nose or bolt tongs.
Tongs, angle nose.
Fire irons, poker, slice, and rake.
Calipers, gages, trimmers, etc.

These tools are made in different sizes, together with other special appliances suitable to any particular character of work manufactured. Each forge or hearth should be provided with a complete set of these hand tools, for which appropriate racks are provided.

There is a distinction made in working wrought iron and steel into required shapes, and the general subject of "The Forge" is usually divided into two heads, viz.: *Blacksmithing* or, as usually termed in England, *smithing*, and *forging*. The first term is usually applied to the manufacture of such small work as can be done at the blacksmith's fire, with light tools, while the second term is usually applied to the working of material that must be heated in

closed furnaces, and worked under heavy steam hammers or hydraulic presses. The product in either case is in general called a *forging.*

The *heating furnace* employed in a large forge is of a type similar to the *reverberatory furnace* shown in Fig. 3, and consists of a rectangular grate and a fire chamber connected to the hearth, and a flue leading to the stack or chimney. This furnace is used for heavy forgings under the steam hammer; the material to be worked, usually in the form of *slabs,* being placed on the hearth, and when sufficiently heated is withdrawn by means of larger balanced tongs, or a *porter bar,* supported and carried by overhead cranes.

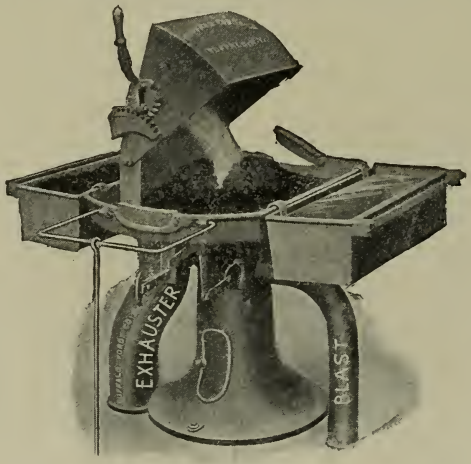


FIG. 98.

Blacksmith's Forge or Hearth.—A common form of this hearth is built up principally of brick, and consists of a *hearth,* a blast nozzle, commonly called a *tuyere,* opening under the iron hearth, which is bowl-shaped in the center, for the fire in which the work to be heated is placed. The fuel lies in a small bank in front, and from which it is fed to the fire as required. A hood surrounds the forge overhead, from which leads a pipe or duct to the smokestack, by which means the forge gases and smoke are carried away.

The coal used in the forge is good quality bituminous, coking easily, free as possible from sulphur, and forming but little clinker. The green coal is broken into small pieces before using and well

dampened with water, thus making it adhere in coking, and preventing the fire from spreading out, by surrounding it with the damp coal, well packed around the edges, and keeping out the blast. By this method we have a center fire where the iron is being heated; surrounding this a ring of coal where coke formation is in progress, and beyond this a circle of green coal.

This method is known as *open-fire* working, and can only be used for short intervals without cleaning and re-building. A *stock fire* is one that can be worked for several hours, by first coking by slow burning a quantity of green coal, then removing this to one side, a block of the size of the fire required is placed in the hearth over the

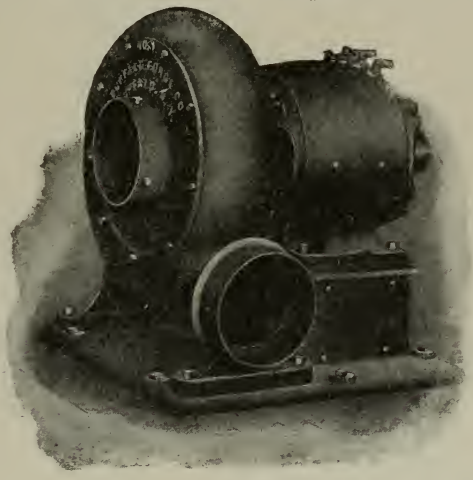


Fig. 99.

tuyere, green coal packed hard around it at the front and back ends, the block removed, and fire started in the space made by the block, and coke added. Loose coal is supplied from the front end, while the *stock* gradually burns away toward the rear, thus lasting for some time.

When a forge is temporarily not in use, the fire should be *banked* by raking up coke over the fire and covering it with green coal, thus maintaining the fire alive, and at the same time producing coke for the fire when it is needed.

In working a forge care should be taken as to the quantity of air supplied. If the blast is excessive, the surplus oxygen, not

combining with the fuel in combustion, will combine with the heated iron in the fire, forming iron oxide or scale, which in welding would prevent a union of the parts to be welded.

In the equipment of the shop in the Engineering Building, instead of adopting an overhead pipe system of smoke removal, with its cumbersome appearance and obstruction of view, a down-draft equipment was adopted. This system consists of a blower and an exhauster in connection with underground pipes or ducts leading to each forge. The blower furnishes the blast for the tuyere in the forge, which can be opened or closed by a convenient handle

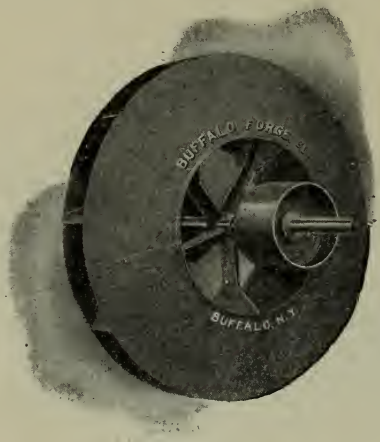


FIG. 100.

attached to the forge, while the forge gases are drawn out through another pipe in connection with each forge, by the exhauster. An adjustable cast iron hood is fitted to each forge over the exhaust pipe, and may be moved close to the fire, or drawn back according to the work performed, as seen in Fig. 98.

Blower.—A type of exhauster used for forge fires, etc., is shown in Fig. 99, while a representation of the blast wheel with its shaft and pulley is given in Fig. 100. These blowers, instead of being belt-connected to a driving shaft, may be directly connected to an engine or electric motor.

Anvil.—The anvil, Fig. 101, is made of wrought iron or mild steel with a working face *A* of crucible steel, about three-eighths

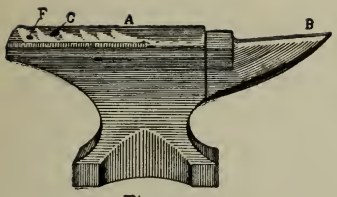


Fig. 101.

Fig. 102

Fig. 103

Fig. 104.

Fig. 105.

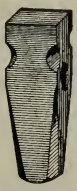


Fig. 106.

Fig. 107

Fig. 108.

Fig. 109

Fig. 110.

Fig. 111.

Fig. 112.

Fig. 113.

Fig. 114

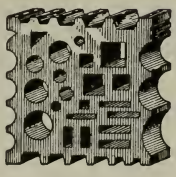


Fig. 115

Fig. 116.

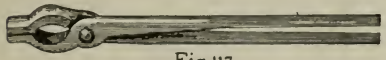


Fig. 117.

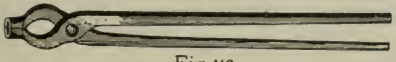


Fig. 118.

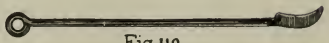


Fig. 119

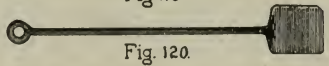


Fig. 120.

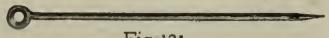


Fig. 121.

of an inch thick, welded on and hardened. The *beak* or *horn B* is not steel coated. The square hole *C* at the ends is to receive the bottom tools, while the circular hole *F* is used in punching. Anvils are listed commercially by their weight from 100 to 400 pounds.

Hammers.—The hammer used by the blacksmith is made of various sizes, usually of the *ball-pene* shape shown at *A*, Fig. 183, and the size in common use weighs from two and a half to three pounds.

The sledge hammer is used by the *striker* or helper, weighs from eight to fourteen pounds, and may be of the three shapes illustrated in Figs. 104, 102, and 103, *double-faced, straight-pened,* or *cross-pened* sledges.

The *set hammer,* Fig. 106, has either a square or circular flat face; it is held in place on the work, and struck with another hammer. This tool is used in finishing up work, or in reducing or setting it down.

Chisels.—For cutting cold metal the cold chisel, Fig. 107, is used, while for hot metal the chisel shown in Fig. 108 is employed. The former is blunter than the latter, which is drawn down to a thin edge as shown. The *hardie,* shown in Fig. 109, is also used for cutting and is shaped with a projection at the bottom so that it can be inserted in the square hole in the anvil.

Flatters, Fullers, Swages.—The flatter, Fig. 112, is used for flattening or finishing up the flat straight faces of a forging. *Fullers* and *swages* usually go in pairs, Figs. 110 and 111, as *top* and *bottom* tools, the stem or projection of the bottom tool fitting easily into the square hole in the anvil face, while the top tool is furnished with a handle. The work is held on the bottom tool, while the top tool above is struck. Figs. 113 and 114 are top and bottom swages, shaped for finishing round work, and are made in various sizes to suit the shape and size of the work called for. In the use of these top and bottom tools, the smith is employed in holding the material and top tool, the hammering is done by the striker or helper, and this method is called *working double handed.* In ordinary forging, when a tool is not used, the work is held in the tongs by the smith with one hand, while the hammer is used with the other.

The *swage block,* Fig. 115, is quite an important tool, made in a number of forms of cast iron or cast steel, and is used in forging and finishing a variety of work, where special tools would otherwise be required.

Tongs.—There is a great variety in the shape and size of tongs, dependent upon the character of the work on which they are to be used. They are generally modifications of the three general types, such as *flat-nosed* tongs for holding flat iron, Fig. 116, *round-nosed,* Fig. 118, for round iron, bolts, etc., and *angle-nosed,* Fig. 117, for square iron.

Punches.—Two kinds are used for punching hot metal—the *hand punch* for punching small holes in thin material, consisting of a piece of round or octagon steel, forged down tapering, the end being slightly smaller than the hole to be punched. The taper is uniform and the extreme end is square across the face and not rounding. For heavier work a punch similar in shape to a hammer with a pointed end, and furnished with a handle, is used with a sledge and helper. The punch is driven about half way through the material lying flat on the anvil, then turned over and punched from the opposite side, the bulge from the first half punching locating the hole.

The following terms are used at the forge:

Drawing down means reducing a thick bar of iron or steel to any required diameter, either by hand hammers, steam hammers, or rolling mills.

Upsetting is the reverse of drawing down, and consists in thickening a bar or rod, or in thickening it in parts, such as the middle or ends.

Scarfing.—This operation is used in *welding* or joining two pieces together, and consists of upsetting or beveling. If the ends of two bars are to be welded, it is necessary to upset the ends so that the succeeding hammering will not reduce the junction below the required dimensions. After upsetting, the ends are beveled by a fuller or hammer.

Drifting Out.—To drift out a hole is to enlarge it by means of a taper, round or square tool, called a *drift* or *drift pin.*

Butt Weld.—If a rod or bar is welded to another bar, so that the joint is at right angles to the bar, it is called a butt weld.

Tongue-Joint.—This joint is made by cutting open the end of a bar to be welded to another, whose end is tapered to fit the opening, and then welding the two bars together.

Heating and Welding.—Wrought iron and mild steel, when heated, become softer, and when the temperature is increased to a point that pieces will adhere to each other, on coming in contact; this point is known as the *welding heat.* If the heating is carried much beyond this point the metal will burn, that is, begin to break up or crumble, with a rough, spongy appearance, and for working purposes is worthless. Good wrought iron can stand better an increased temperature than the mild steels containing a greater proportion of carbon. Care should be taken in working wrought iron or steel not to continue the hammering after the heat is gone, as cold hammering has a strong tendency to produce crystallization, with its consequent weakness.

In welding wrought iron, as has been stated, the heating is continued with the two parts to be united, until a temperature is reached, when on the two parts being brought together they will stick, a temperature of from 1500° to 1600° F., or just when the iron commences to throw out sparks. The two parts are then hammered together on an anvil, and if the work is properly done the union will be as strong as at any other part.

In making a weld, the ends of the two parts must be *upset* and then drawn out into a *scarf,* in order not to reduce the area of the section by hammering, and to present a greater surface for the weld. Both parts to be welded should be brought to the proper heat at the same time, which is arranged by properly manipulating them in the fire. If they are too cold, hammering will not unite them, and if too hot they will be burned. Also, they should be evenly heated all the way through. Every thing should be in readiness before starting to weld, with fires clean, anvil clear, and tools handy. The blast is then shut off, the two parts removed from the fire, properly placed together, and united with rapid blows of the hammer; the thin part first, as this part cools first. If cinders or dirt get between the two welding surfaces a bad weld will result with its accompanying weakness.

In heating iron or steel for welding, an oxide or *scale* is formed on the surface, and in iron welding the temperature can be raised

sufficiently high to melt the oxide, which is forced out by the hammering. With steel, if the temperature is brought high enough to melt the oxide, the steel would be burned. To overcome this difficulty a flux is used, usually borax, or a mixture of sal ammoniac and borax, sprinkled over the parts to be welded, then the piece brought to the proper temperature, usually when it has reached a yellow heat, and the weld made. The action of the flux is twofold: As it is dissolved by the heat it acts as a protective covering, preventing oxidation, and also dissolves the oxide formed, as the oxide melts

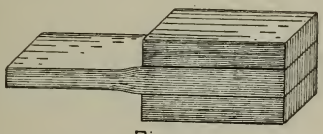


Fig. 122

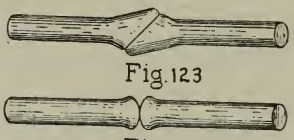


Fig. 123

Fig. 124.

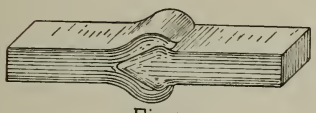


Fig. 125.

Fig. 126.

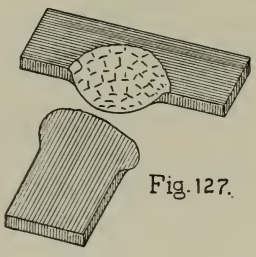


Fig. 127.

at a lower temperature when combined with the flux, and as before is driven out by the hammer.

The types of welding in general use are: *Fagot welding,* the *scarf weld,* the *butt weld,* the *split weld,* and the *T weld,* for both round and square stock shown in Figs. 122 to 127.

Fagot Welding.—In this method scraps of various sizes are bound together by wire into a square or rectangular shape, brought to a welding heat in the furnace, and then welded together into a solid mass with a power hammer. When a large forging is to be made, these masses are piled and welded to each other, forming one large piece, from which the forging is made similar to that shown in Fig. 122.

Lap scarf welding is shown in Fig. 123; the ends should be upset, scarfed, and well hammered together under a welding heat, as formerly explained, the scarf being made slightly convex in order to prevent a pocket being formed in the center of the weld, thus preventing impurities from being forced out. The indication when welding heat is reached can only be obtained by experience at the forge, the color as heating proceeds gradually grows lighter, until at welding heat the color is almost white and the iron just about sparking.

Butt Welding.—Fig. 124. The weld in this case is made without any scarfs, the ends slightly upset and rounded, brought to a welding heat and united by being struck on the ends. The upset part is then brought down to size at a welding heat, by working with the hammer. A butt weld is not as strong as a lap weld.

Split Weld.—In Fig. 125 is shown a split weld, the ends of the stock in this case being first upset and scarfed. One piece is then split, forming a V, while the other is shaped to a point or edge with the base slightly bulged from the size of the stock in order to prevent the pieces from slipping apart. The parts are heated either separately or driven together before being placed in the fire, and when the welding heat is attained, united by the hammer. In welding tool steel to iron the method of separate heating is employed, together with the use of a flux, as tool steel has a lower welding temperature than wrought iron or low steel; the latter can be raised to its proper welding heat.

In welding steel more care is necessary regarding its heat than with wrought iron or mild steel, owing to the danger of burning the metal. As in the case of wrought iron, experience is the only guide. In general, the welding temperature for tool steel is reached at about a bright yellow heat; if the heat is continued until sparking occurs, the metal will burn and will easily disintegrate under light blows from the hammer.

Annealing.—The object of annealing structural steel is for the purpose of securing homogeneity of structure that is supposed to be impaired by unequal heating, or by the manipulation necessarily attendant on certain processes. The objects to be annealed should be heated throughout to a uniform temperature and uniformly cooled.

With the above description of the tools used, the following is the method for simple forged work as conducted in the Practical Exercises in the Engineering Department of the Naval Academy.

Calculation of Stock Required.—To avoid waste and yet to be assured that sufficient material has been cut off for a forging, especially in cases where it is necessary to cut off the exact amount required, the preliminary step is to examine the drawings or sketches, and calculate the amount required. Where the parts are regular mathematical figures the material can be easily calculated; where the parts are complex with irregular curves, they should be divided up into parts and separately calculated or measured, by laying off the separate parts of the work full size, and with small flexible wire placed along the center of the figure, then after straightening the

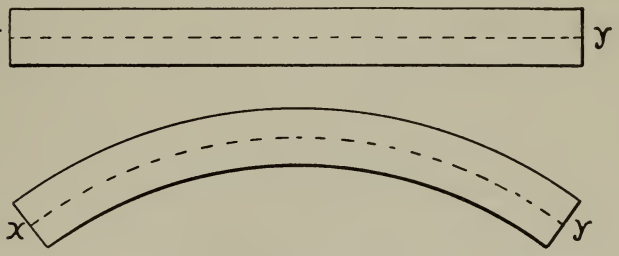


FIG. 128.

wire, the quantity required can be directly measured. Mechanical measuring wheels run over the work are also employed. These wheels have a pointer and register, graduated in accordance with the diameter of the wheel used, and from the revolutions or fractions thereof, made in passing over the drawings, the amount of stock is registered.

It has been stated above that in measuring for the stock, the length of the center line is taken on the bent or curved figure. This can be readily seen by taking a straight bar and bending it as indicated in Fig. 128. The effect of the bending is to lengthen the upper part of the bar beyond its original length, and to shorten the lower side. This deviation gradually grows less, and within the bar of metal there is a part where there is neither extension nor compression, and that part remains the original length; this line *xy*

is known as the *neutral axis,* the fibers on one side being in tension and those on the other in compression, and this neutral axis passes through the center of cross-section of the bar. Hence, in all calculations or measurement for stock, calculate on the length of the neutral axis.

In the case of an eye made of 1″ round stock and three inches internal diameter, the stock required would be that circumference due to a 4″ diameter.

For a right-angled bend of 1″ stock, as in Fig. 129, the legs are 6 inches and 8 inches. It is apparent that stock 13 inches long will make the required forging. Allowance is made for waste in working, in the welding, upsetting, the amount burnt off or wasted in scale, and depending upon the number of heats, the amount of overlap, etc., for which allowance, experience is probably the best

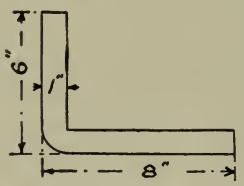


FIG. 129.

guide, and is obtained by watching the operation in the various classes of work.

An allowance is also made on the drawings furnished as *finished sizes.* As these drawings show the finished object as it leaves the machine-shop, all parts requiring *machining* or *finishing* must have additional metal to permit removal in the operation of finishing.

For volume work in heavier forgings, the total volume equals that of the finished forging plus an amount allowed for losses in forging, as the volume remains the same irrespective of the forged shape.

Weight of Forgings.—The volume multiplied by the coefficient, pounds per cubic foot or pounds per cubic inch for steel or wrought iron, gives the weight in pounds.

	Pounds per cu. foot.	Pounds per cu. inch.
Cast iron	450	.2604
Wrought iron	480	.2779
Steel	490	.2936

Upsetting.—By *upsetting,* the piece is worked so that its length is shortened, thus increasing either its width, thickness, or both. The usual method of upsetting, after heating the metal, is to stand it on end on the anvil, and strike on the upper end, or in the case of heavy pieces, to swing the end and ram it against the side of the anvil. The work will bend in the operation and should be straightened by hammering before continuing to upset.

The metal should be well heated, and the blows heavy, otherwise the effect will not reach the center. In upsetting the ends only, or the center, or any one part, only that part requiring upsetting should be heated; and in short pieces requiring central upsetting only, if it is not possible to confine the heat to that part, heat the whole, and with tongs holding the piece at the middle, dip the ends into the water-bucket.

Drawing Out.—In *drawing out,* the metal is drawn out by heating and hammering; its length is thus increased and the width or thickness decreased. The material is fully heated, laid on an anvil, and hammered; as the width is also increased as well as the length, the work is turned on its edge during the operation, and kept within the width dimension called for. In drawing out round bars, they should first be forged down square near the desired size, then the corners flattened, making the piece octagonal, and finally it is finished up round. Unless this procedure is carried out the work is very liable to split.

Following welding comes bending into curves and angles. In making a simple bend the stock is marked with a center punch at the point at which the bend is required. It is then laid flat on the anvil with the mark nearly to the edge of the anvil, as the bar will draw out over the edge in bending. Holding the work firmly in this position by means of a sledge on its upper side, it is hammered down to the required angle.

Bending an Eye.—Measure the stock required for the eye portion and mark it off on the work. It is equal to the circumference of a circle, due to a diameter of the inner diameter of eye plus one thickness of material. With this mark on the edge of the anvil make a right-angled bend. Continuing heating as required, bend the bent part outwardly at the extreme end, and follow it up by bending

around the horn of the anvil until this end is brought around to the shank. The operation is illustrated in Nos. 1, 2, 3, 4, Fig. 130.

S Hooks.—A similar example to the preceding is an *S hook*, Fig. 131, and the method of work is as follows: Measure, cut, and mark the stock, calculating for the circumference of the two circles desired. At the middle of the length of the bar bend it at right angles and work an eye out of each leg of the angle, as explained in

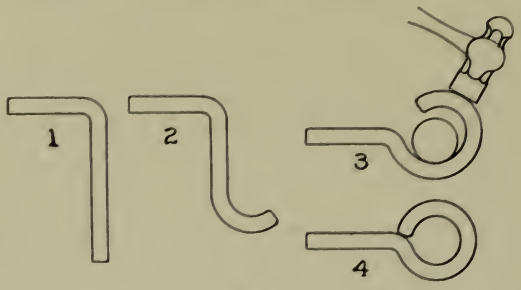


FIG. 130.

the preceding, commencing at the extreme end as before and finishing up one end before starting to bend the other.

Ring-forging.—After cutting the stock required, the two ends are scarfed, one in the reverse direction to the other. After heating, each end is bent for about one-third the length of the piece, over the horn of the anvil to the form shown in Fig. 132-2. A heat is then taken on the straight middle part, and the ring brought

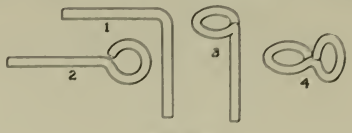


FIG. 131.

to the shape shown in Fig. 132-3, the two scarfed ends overlapping each other. A welding heat is now taken at the scarfs, the ends welded together, and junction rounded and finished up with the hammer.

Chain-making.—In light chain-making the stock is first bent into a U shape with legs equal in length, then gripping at the bend of

the U, the two ends are heated, scarfed, and bent into shape, the two scarfed ends are now brought together, re-heated, and welded together. The different steps in the operation are shown in Fig. 133. For a chain, or series of joined links, the second link is made, as in the preceding, before welding the scarfed ends are opened sufficiently for the first link to enter, then closed up and heated and welded. In like manner the succeeding links are made and joined.

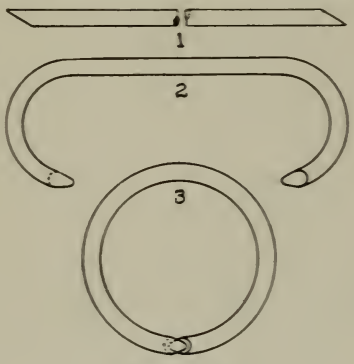


FIG. 132.

For commercial purposes the product is largely increased by the use of machinery, as follows: A long bar of the proper thickness is wound into a spiral of links on a *link-winding machine*, then

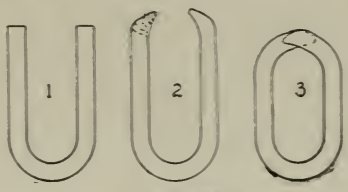


FIG. 133.

transferred to a *link-cutting machine*, where the links are cut apart, the scarfs being formed in the process of cutting, thus the smith is saved the process of cutting, bending, and scarfing the links, and doing away with the necessary heatings under the hand process.

In welding the links, the smith selects one having reached the welding heat, and hooking it through the link last welded, places

the open end over the lower die of a compact chain-welding machine, a similar die being fitted to the hammer-arm. Pressure on a treadle releases the hammer-arm and the impact of the blows force the scarfed ends closely together and welds the link, the dies reducing the size of the weld to the same size as the rest of the link. About ten blows of the hammer-arm are required to make and finish the weld, the smith turning the link over and back on the lower die. The output per day is about four times that by the hand process.

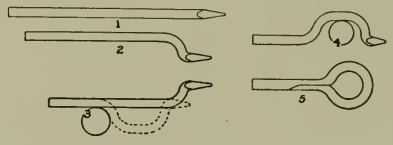


FIG. 134.

Welded Eye Bolt.—In making a lap-welded eye bolt, scarf one end of the bar and measure the stock required, dependent upon the size of the eye, and center punch this distance from the inner end of the scarf. Then working on the horn of the anvil, make the bend shown at No. 2, Fig. 134, and that at the center-punch mark, as in No. 3. After again heating, the work is brought over the anvil

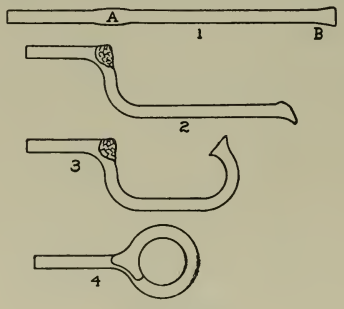


FIG. 135.

horn and hammered around it until the scarf is brought to place on the shank. A welding heat is now taken on the scarf and shank at the part in contact, and the two parts welded together with the ball end of the hammer.

Solid Eye Bolt.—Due to the circumference of the eye required, measure and mark from *A* the stock, as previously explained. Upset the part *A*, Fig. 135, sufficiently for an ordinary lap weld. Heat

and upset the end B to the same extent. Bend the stock at the middle of the swelled part A with a radius equal to that of the eye, and scarf A with the pene of the hammer. Heat and bend the end B to the same radius as made at A, turn it and scarf the end with an opposite scarf to that at A. Heat the stock and bring the end around over the horn of the anvil, until the two scarfs are brought together, one part of the end scarf projecting below on the shank and the other part lapping around on the circumference of the eye, working them to place by heating as required. When the scarfs are in position, take a welding heat and quickly make the weld as follows: Lay the eye bolt flat on the anvil and, with the flat face of the hammer, strike the blows on the scarf, turning the eye bolt from one side to the other, then with the ball pene weld the inside of the eye on both sides, and with the same welding heat, transfer

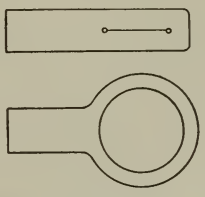


Fig. 136.

the eye to the horn and weld the parts around the fillets with the ball of the hammer. Take a red finishing heat and with a mandrel round the interior of the eye and finish up the piece.

Weldless Eyes or Rings.—One method is that by *split-forging,* Fig. 136, in which a flat bar is taken and the end rounded up to size. Two small holes are then punched in the stock, spacing them to allow for the hammering in finishing, and the material between them split with a hot chisel. The split is then opened up with a punch or taper mandrel and the eye finished over the horn of the anvil.

Weldless eyes or rings can also be made by forming the necessary stock into flat shapes and punching a hole through the center, then placing the forging on the horn of the anvil, it is worked out to the desired shape and size.

Twisting.—In twisting, the metal is heated uniformly for the whole length to be twisted. It is then gripped with tongs or in a

vise at the point where twisting is to commence, while the other part, where the twist is to end, is gripped with a pair of tongs and twisted the necessary amount. Care must be taken in gripping the metal at the exact points required, also that the metal is at a uniform heat throughout the length to be twisted, or there will be non-uniformity in the twist. In Fig. 137 is shown the appearance of stock of different shapes after twisting.

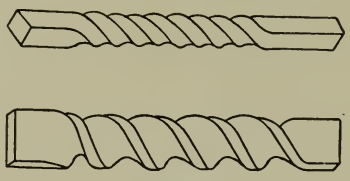


FIG. 137.

Forming Shoulders.—Mark the position on the stock where the shoulder is desired and bring this mark on the edge of the anvil, then place a set hammer over the stock so that its edge comes directly over the edge of the anvil. By striking the set with the sledge and turning the piece during the operation, the shoulder is formed, Fig. 138.

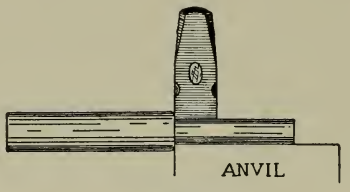


FIG. 138.

Bolt-making.—In making bolts two methods are employed; in one case by upsetting an end for the head, and in the other case by welding a collar around the end of the stock. The first method is preferable, and an upset head is stronger than a welded head.

In making an upset head-bolt, the stock is first heated at the end, and upset to the shape shown in No. 2, Fig. 139. It is then slipped into the opening of what is known as a *heading tool,* shown at *A,* and is made with one side of the head of the tool flush with the handle, and the other side projecting slightly above it. The tool

is placed directly over the hardie hole in the anvil and the body of the bolt thus projects down through the heading tool and hardie hole, the upset end remaining above the tool. The upset end is now flattened down by the hammer on the tool and then forged square or hexagonal as required.

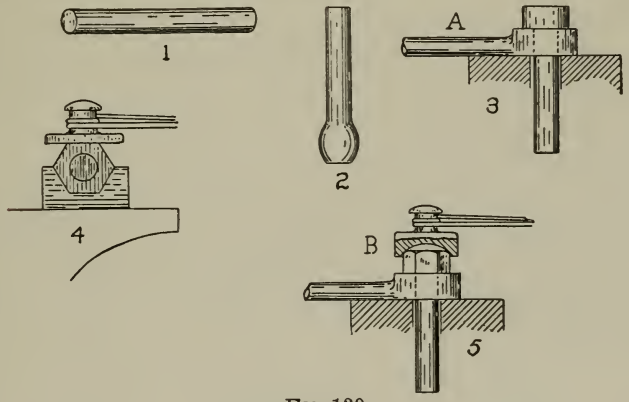


FIG. 139.

In making a welded-head bolt, Fig. 140, a piece of square iron is bent around, and of a size so that when slightly opened it slips easily over the body of the bolt stock. The bolt end is now heated to a welding heat, the ring somewhat cooler, and the latter is then

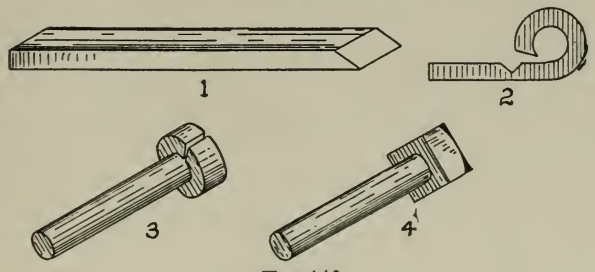


FIG. 140.

driven on the bolt end. The two parts together are now *slowly* heated in order that the end within the collar may be brought to a welding heat without burning the outside of the collar. When heated sufficiently to stick, the ring and bolt end are welded together and the head shaped, care being taken to hammer the head

square and not round. The head is generally *chamfered,* that is the top corners of the head rounded off. This is usually done by a cupping tool, No. 5, Fig. 139, and which is similar in shape to a set hammer, with a recess or cup turned out of the bottom face.

For the proportions of nuts and bolt heads, there is no generally adopted system, but different manufacturers use their own rules. Unwin gives for the general ordinary proportions:

Diameter across flats, rough, $D = 1.5d + .125$. Hexagon or square.

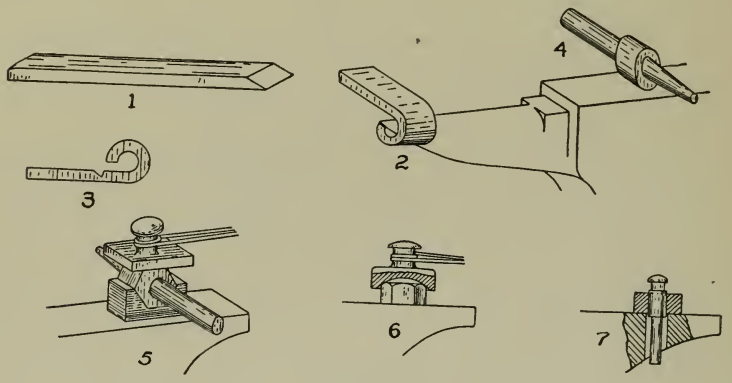


FIG. 141.

Diameter across flats, finished, $D = 1.32d + \frac{1}{8}$ to $1.5d + \frac{1}{16}$ Hexagon or square.

Diameter across angles, $D_1 = 1.155D$. Hexagon.

Diameter across angles, $D_1 = 1.414D$. Square.

Usual height of nut $= d$.

Thickness of bolt head $= .75d$.

The dimensions of the head are the same for all bolts of the same size irrespective of the length, *and the length of the bolt is always measured from under the head.*

Nuts for bolts, if made by hand, are generally forged in the shape of a ring. Stock of a width equal to the depth of the nut is first scarfed at one end, then heated, bent round the horn of the anvil, and after nicking it with the chisel it is broken off. It is then brought to a welding heat, lifted out on a mandrel, and the ring welded. It is next re-heated, the sides swaged to shape and

cupped on one end, and finally the hole is made to the correct size by a finishing mandrel driven through the nut and a hole in the anvil. The different stages in the process are shown in Fig. 141. This method of making a nut by hand is given as an example in forging, but it should be mentioned that in commercial use, standard bolts, nuts, and rivets are made by automatic bolt-machines, in which the cost is greatly decreased while the output is very greatly increased per given time.

Forging a Pair of Tongs.—To forge a pair of flat-lipped tongs to take in work, say up to one inch, take a bar of one inch square iron. Lay about two inches on the inside edge of the anvil and work down the thickness to one-half inch, at the same time drawing it so as to maintain the width one inch. With the same heat turn the bar at right angles with the part just worked, extending it beyond the outer edge of the anvil, and flatten the bar just behind

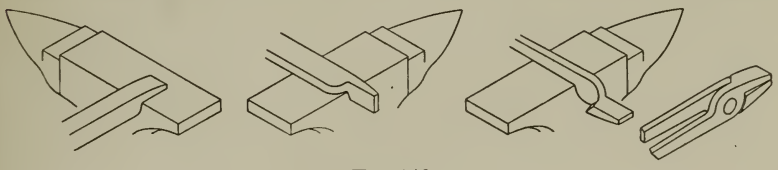


FIG. 142.

to one-half inch. With another heat move the bar forward on the anvil about two inches from the last work, and turn the bar at right angles to its last position. Forge about three inches of the remaining part to about three-fourths inch by one-half inch. Cut off about four or five inches, and make another jaw in exactly the same manner, and scarf the handle end of each. For the handle select a piece of one-half inch round iron, scarf one end and weld it to one of the jaws. Proceed in like manner for the second. Round up the eyes, punch a five-eighths inch hole through each, rivet up, re-heat, dress the jaws parallel, and cool. The different operations are shown in Fig. 142.

In addition to the working down of iron and steel, there are several operations performed at the blacksmith's forge, viz.: The methods of *hardening, tempering*, and *annealing*. From the foundry methods it has been seen how cast iron is hardened on the surface by chilling in the mould. With wrought iron and steel the

hardening is performed on the completed object, after all the work of heating and finishing has been performed.

Case Hardening.—This is the name given to the process whereby wrought iron or machinery steel is superficially converted into high carbon steel, for a depth of from one-eighth to three-sixteenths of an inch below the surface. As the hardening property possessed by steel depends upon the presence of combined carbon, and since in wrought iron and machinery steel this element is nearly eliminated, any hardening properties are practically absent. In case hardening, carbon is added to the surface of wrought iron, thus converting that portion into steel, which may be hardened by cooling suddenly from a high heat, and producing material with a very hard outside working surface, while the inside is composed of the softer ductile wrought iron, capable of standing vibration and shock. In case hardening, two methods are in general use, one the animal charcoal process and the other the cyanide process.

Charcoal Case Hardening.—Any animal charcoal from burnt horns, hoofs, bones, leather scraps, etc., reduced to a powder, will answer for a material rich in carbon. The articles to be hardened are finished and polished, then placed in an iron box, and the animal charcoal well packed around them, using care that the articles do not touch each other. The box is then tightly closed, luted with clay, inserted in the fire, and brought gently to a red heat. After the box becomes properly heated, it is kept at that temperature from one to three hours and the articles then dropped into moderately cold water. The deeper the coating desired, the longer is the heat kept up in the case-hardening box. The process is similar to that of the *cementation process* of converting cast iron into steel, Chapter II, the only difference being that the heating is continued only long enough to coat the surface with steel, instead of steeling it throughout.

Cyanide Case Hardening.—Small articles are case hardened by heating them to redness and sprinkling or rubbing them in powdered yellow prussiate of potash (potassium ferro-cyanide), reheating them for a very short interval, to let the cyanide work in, and then quenching them in water. Another method is to melt the cyanide in a ladle or pot; heat the pieces to be hardened, place them in the cyanide, and leave them there for a period depending

upon the depth of the hardness desired, and then removed and plunged into cold water. The cyanide process gives but a thin shell of steel on the surface or a superficial case hardening.

Hardening and Tempering Steel.—Tool steel can be hardened by heating it to a cherry red, and then suddenly cooling it by plunging it in water. The material should be heated uniformly throughout the mass, and for quenching there should be plenty of water, running water being better, while the quenching should be done immediately on removal from the fire. The exact degree of heat to which the steel should be brought depends upon the percentage of the contained carbon, and also largely upon the experience of the operator; in general, the greater the amount of carbon, the lower is the heat required, and the faster the steel is cooled the harder it becomes. In hardening steel, the material is subjected to great shocks and strains, and if improperly done the piece is liable not only to warping and bending but also to fracture.

Liquids other than water are also used for quenching; oil is used where toughness and not extreme hardness is desired, and is almost universally used for springs, leaving the piece in somewhat of a tempered condition. Brine will harden to a greater degree than fresh water, and mercury will give the greatest hardness of all.

After a tool is hardened as above, it is too hard and brittle for most purposes, and must be *tempered,* or softened, to relieve some of the strains, reduce brittleness, and increase the toughness. The operation is known as *drawing the temper,* and is done by slightly re-heating the previously hardened steel, by holding it over the fire, or in contact with a large piece of steel or iron previously heated for the purpose, until the surface turns to a color corresponding to a certain temperature, which indicate the degree of hardness obtained. The steel is then plunged into cold water and that hardness retained.

The temperature to which a piece of hardened tool steel should be re-heated and then immediately chilled is given in Table I, from which it will be seen that at 430° F. the tool steel is only slightly softened and toughened and is of the hardness required for planer tools for steel, hammer faces, etc. If the heat is raised to 460°, the metal is softer and suitable for taps, dies, chasers, etc., while at a temperature of about 650° the temper is all gone and the

metal is soft and unfitted for tools of any sort. Hence, when drawing down the *temper,* the *softest* tool is the one which is cooled at the *highest* temperature, and the *hardest* that cooled at the *lowest* temperature.

Temper Colors.—The temperature which the tool has assumed may be ascertained by the color which appears on the brightened surface of the steel. If a brightened piece of steel or iron hardened or unhardened, be heated in the air, a thin film of oxide forms on the outside, which changes in color as the heating progresses. First is noticed a very pale straw color; then in order, a darker straw, brown yellow, light purple, dark purple, dark and

TABLE I.

Hardness	Color	Temp. F.	Use of Tools
Very hard	Cherry red	1650°	For preliminary hardening.
Soft	Pale blue	600°	
Elastic.	Dark blue	570°	Screw drivers. Saws for wood. Springs.
	Dark purple	550°	Cold chisels C. I. Hack saws. Firmer chisels. Axes.
	Light purple	530°	Cold chisels W. I. Augers.
	Yellow purple	520°	Flat drills for brass. Twist drills. Plane Irons.
Hard...	Brown yellow	500°	Shell reamers. Gages. Drifts.
	Dark yellow	490°	Forging dies, press. Shear blades. Screw cutting dies. Taps.
	Straw yellow	460°	Flat drills for steel and iron. Planer tools for iron. Drills for brass milling cutters. Boring cutters. Rock drills.
	Very pale yellow	430°	Planer tools for steel. Light turning tools. Steel engraving tools. Hammer faces. Scrapers. Burnishers.

finally pale blue. These colors furnish a valuable index of the temperature and serve to show the point at which the heating must be arrested.

To Temper Cutting Edges Only.—For tools, such as lathe tools, cold chisels, drills, etc., where only the cutting edge is required to be tempered, the following is the procedure: For example, a cold chisel is forged from a round or octagon steel bar, and drawn down at a low heat to a flat edge, as at *A*, Fig. 143. The edge only is required to be tempered, while the body of the chisel is to remain in its normal condition. The cutting end is heated to the proper hardening heat for two or three inches back from the edge, and the

part *A-B*, about two inches of the point, quenched in cold water, thus becoming hardened. The chisel is withdrawn, the end rubbed off with emery cloth or a stone in order to brighten it. As a part of the chisel above *A-B* is red hot, the heat will gradually travel towards the cutting end, and the various colors will successively appear. When a deep bluish-purple appears at the cutting edge, the tool is entirely plunged in water and the correct degree of hardness obtained. A flat drill is heated similarly, except that the final dipping or quenching takes place when the temper color of a straw-yellow is reached.

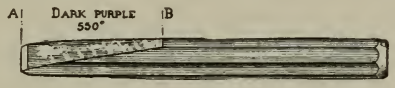


FIG. 143.

There is another class of tools, such as dies, reamers, screw taps, milling cutters, etc., which are tempered to a uniform hardness throughout, or for a considerable part of their length. In these cases the whole part is brought to the hardening heat uniformly through the mass, cooled, and hardened throughout. The surface is then polished and the temper drawn by placing the tool on a block of heated iron, turning the tool constantly until the surface shows the proper temper color, when it is instantly cooled.

FIG. 144.

In the case of a screw tap, the shank is kept soft, while the threads are tempered hard. In this case the tap, Fig. 144, having been hardened and polished, a tube is procured to fit loosely over the tap. The shank is picked up by the tongs *A*, whose jaws have been heated to a red heat. The tube also having been heated to a dull red. The body of the tap is inserted. Heat having been applied at an earlier stage to the shank *B*, by the time the body of the tap *C* has reached the stage of a dark straw color, *B* will have passed along to a higher position on the color scale, and arrived at a dark blue. At this period the tool is dipped in water, obtaining

the result desired, a color hardness corresponding to a dark blue at the shank, and a dark straw at the threads.

Oil Tempering.—Owing to the care necessary in watching the gradations of color assumed by the metal as the temper is drawn, many large shops have adopted the method of tempering by oil, and gaging the heat by the thermometer. The vessel containing the oil is heated over a fire to the correct temperature, and the hardened parts dropped in and left until the temper is drawn. As the temperature of the pieces can not exceed that of the oil, the temper can not be overdrawn, and it is not necessary to polish the work. On reaching the required temperature the parts are lifted and quenched.

Blazing-off Springs.—Another example of dispensing with the tempering color scale is that of *blazing*. The spring is brought to a hardening heat and cooled in oil. The spring is lifted, and while still covered with oil, it is re-heated until the oil blazes, when it is again plunged for an instant into the oil bath. This is repeated until all parts of the spring are uniformly brought to the same temperature, when it is quenched.

Annealing is the complete softening of a piece of steel, and is the reverse of hardening. It is produced by bringing the steel up to the proper heat color, medium orange, leaving it at that heat until it is heated uniformly throughout, and then allowing it to cool slowly.

At the forge the usual custom after heating is to bury the piece in the cinders and keep it there until it is cooled; a blacksmith has usually near his fire a box containing dry lime or powdered charcoal; the piece is brought up to the proper heat, then removed and buried in the box, where it cools slowly.

In *box annealing* the parts are well packed in granulated charcoal in an iron box, and then taken to the forge and heated to a bright red heat, at which it should be held for some time, depending upon the size of the parts. After this heat, allow the box to cool off slowly, while the parts are not removed until perfectly cool.

Another annealing method for emergency work, but one not approved when sufficient time is available, is known as *water annealing;* the piece is heated until it just shows a red glow and then quenched in water. This leaves the steel soft enough to be worked,

but not as soft as steel annealed by the general method. It is used when the forging must be worked upon immediately and is needed in a hurry.

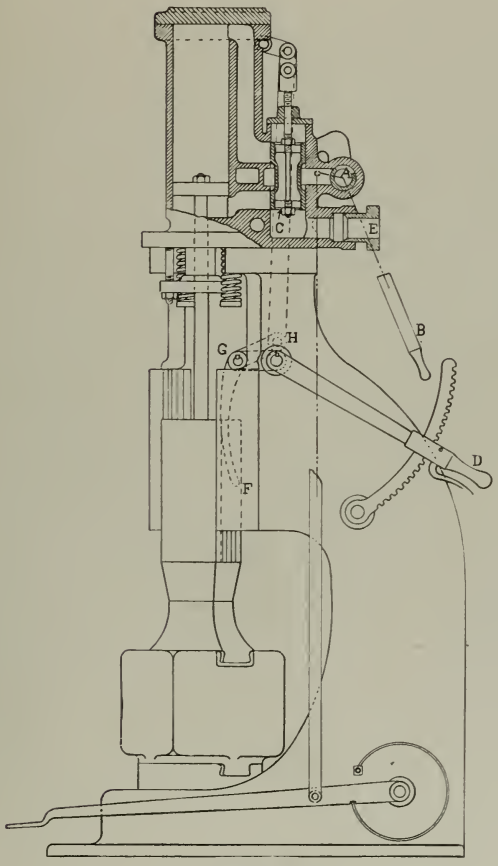


Fig. 145.

Steam Hammer.—In Fig. 145 is seen a small steam hammer, as used in the blacksmith shop, and of the same general type and size as that in the Engineering Building. It is known as a *single-frame hammer,* and size 250 pounds, while in Fig. 146 is shown a *double-frame* 24,000 pound hammer. The size of a steam hammer is indicated by the weight of the piston, piston rod, and the weight of

the hammer head, no account being taken of the steam pressure upon the piston, which considerably increases the falling weight. The

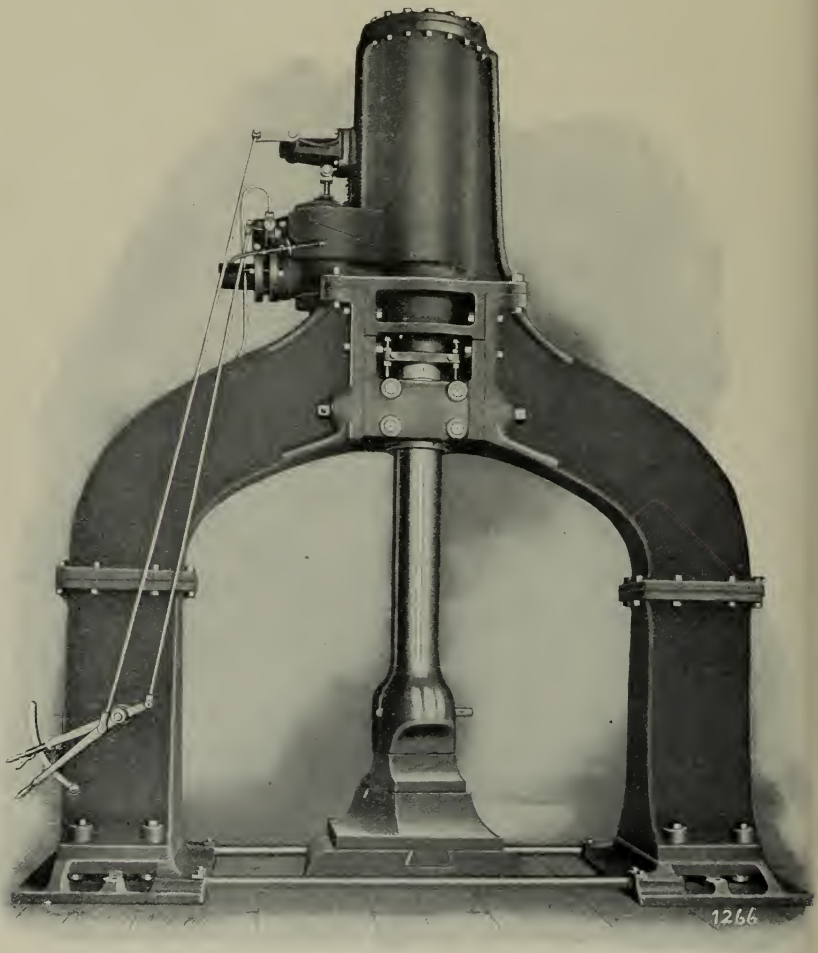


FIG. 146.

anvil is entirely distinct from the frame of the hammer, and rests upon a separate and heavier foundation in order that the anvil may give under a heavy blow, without affecting the hammer frame

or its foundation. The hammer and anvil faces are flat and usually made of tool steel, although chilled cast iron is frequently used.

The valve mechanism consists of an outside valve *A*, opened and closed by the angular movement of the lever *B*. The regulating, or inner valve *C*, is an inside hollow piston valve, and the operation is as follows: The hammer being at the bottom, in order to raise it, the admission valve *A* is opened, the regulating valve *C* brought down by raising the lever *D*, opens the lower end of the cylinder to steam and the piston rises, carrying with it the hammer, while the exhaust steam from the upper end of the cylinder passes out through the upper port, and out through the exhaust pipe *E*. The hammer is driven down by reversing this operation; by moving the lever *D* down, placing the upper port in communication with the steam surrounding the piston valve, while the lower end of the cylinder is then open to the exhaust pipe *E*.

For the self-acting or automatic arrangement whereby the hammer keeps on striking successive blows for any desired period, and continuing to do so as long as *A* is open, the following is the operation: The cam lever *FGH* is fulcrumed at *G* on the short arm of the lever *D*. The tendency of the valve *C* from its weight is to come down, thus admitting steam to the bottom of the cylinder. As the piston rod rises, the hammer head presses against the curved arm *FG*, pushing it to the right, thus raising the valve stem and valve *C*, and admitting steam to the top and driving the hammer down; this operation is repeated automatically as long as the lever *D* is to one side or the other of its central position and *locked*.

The number and extent of the blows are regulated by the lever *D*. If short, quick blows are required, run the lever *D* up, while slower periods are obtained by moving the lever towards the central position, and locking it for the position taken.

The tools used in steam-hammer work are shown in Fig. 147. The tongs should be well made and the jaws fitted so as to hold the work securely. Flat tongs are undesirable as the work is liable to slip out. The turnbuckle or link is slipped over the handle to secure the tongs and turn them. Chisels should be blunt, and the edges usually square and not rounding, nor diamond-pointed, as in a hand chisel. In using the steam hammer the stock should rest flat and solid on the anvil and the part under operation should rest

below the center of the die. As the faces of the hammer die and anvil are parallel and flat, if it is desired to finish up any tapered work, tapering tools must be used. For roughing out, the round side is placed on the work on the anvil and the blow struck by the die coming on the flat part, making a number of corrugations, as shown in the sketch. In finishing the taper the tool is reversed, the flat side being next to the work.

Punches are generally short tapering pins with a groove around the upper part for the attachment of the handle. The punch is driven in part of the way on one side, then the piece reversed and a perforated disc placed on the anvil under the partially-made hole, and the punch driven through.

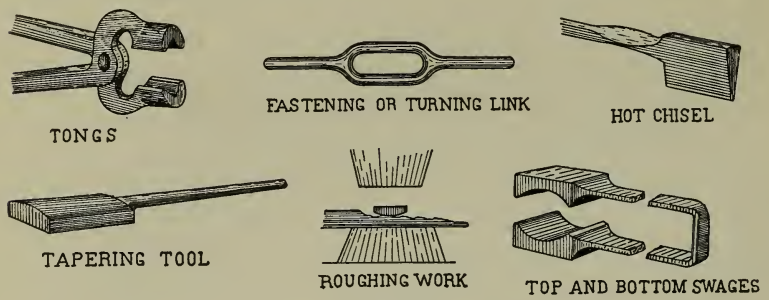


FIG. 147.

Crank-Shaft Forgings.—In forging a crank shaft of iron a start is made from a porter bar, a long tapering bar supported by a crane chain, on one end of which fagots of iron are piled, heated, and welded; this process of accretion is continued, and as the piles of fagots are welded the shaft is roughed into shape.

In the case of a solid forged-steel shaft a start is made from a solid ingot, generally cast with a tong-hold, to which the porter bar is fastened. The ingot used should be as solid as possible and free from blow-holes, cracks, and other defects.

Porter bars, Fig. 150, are separate and distinct steel forgings, forming part of the general equipment of a steel plant, and range in size from 9 to 15 inches in diameter, and from 25 to 35 feet in length.

They are attached to the ingot by means of a *chuck*, Fig. 151, a cylindrical steel casting, the end *A* fitting over the ingot and held

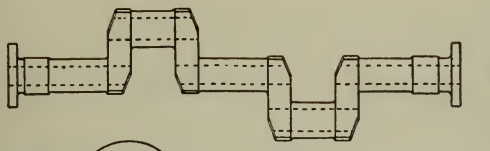


Fig.148.

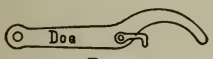


Fig.149.

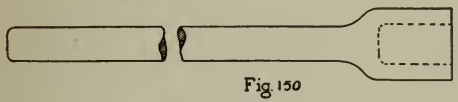


Fig.150

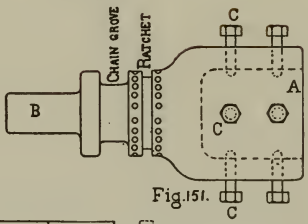


Fig.151.

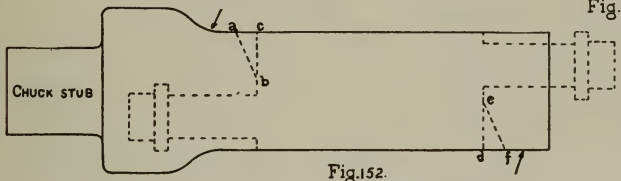


Fig.152.

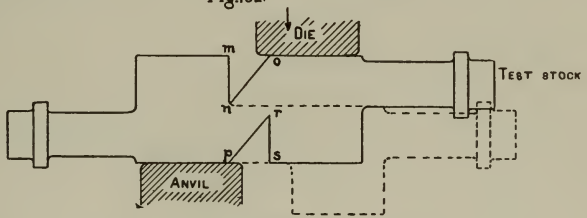


Fig.153.

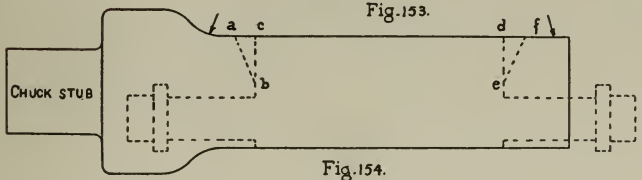


Fig.154.

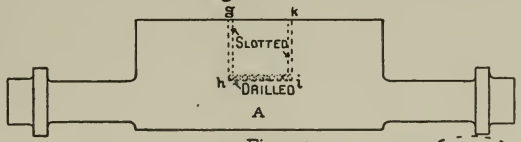


Fig.155

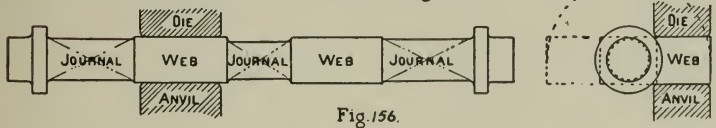


Fig.156.

in place by the set screws *C;* the other end *B* is made with a stub to fit into a recess in the end of the porter bar. Large ingots, 30 tons or more, are cast in moulds whose top parts are reduced in size to form the *chuck stubs,* and will fit the larger chucks without any preliminary press or hammer work. This stub end is always at the top of the ingot, that part containing most of the impurities, and is cut off and discarded after the forging has been well roughened out. During *heats* the chuck end of the forging projects from the furnace, receiving little or no heat. When ready an overhead crane picks up the porter bar, which is fitted with a counter-weight to balance the whole gear.

In forging a double-throw crank shaft with cranks at 180°, a suitable ingot is forged down to a rectangular slab, whose dimensions safely permit the working of the shaft to size. The two ends of the shaft are next formed, and this operation depends upon the manner in which the cranks are to be brought into proper position with each other, by a *shove-over* or a *twist-over,* and depends upon the length of the middle journal. In a two-throw crank, with a short middle journal, the cranks after heating are shoved over, as a twist of 180° in a short, thick shaft tends to weaken or rupture the structure. If the length of the journal exceeds the diameter by 50 percent, the cranks are brought to their proper position with each other with the hydraulic press, after heating, by twisting over. In these two operations the method of cutting the ingot and working to shape is somewhat different.

For a shove-over crank shaft, the end journals are formed by first cutting from the slab V pieces, *abc* and *def,* Fig. 152, and the ends of the slab drawn out and shaped, as shown by the dotted lines. The V's are cut out by cutter bars forced down through the plastic metal by the press or hammer. After shaping, the forging is sent to a slotting machine and V pieces *mno* and *prs* cut out, as shown in Fig. 153, and taken back to the press or hammer plant for the final operation. After bringing the middle section to a bright red heat, it is placed under the press, as shown in Fig. 153, and the plunger die forced down until the middle journal is straightened out and formed in line with the end journals. After this forge finishing, the work is carried to the machine shop and the shaft finished up, by boring out the crank pins and journals,

slotting out the webs to form the cranks, planing the flat surfaces, and turning the couplings, journals, and crank pins.

Twist-Over Crank Shaft.—In this method the operation is somewhat different. Referring to Fig. 154, V pieces are cut from the slab, as shown at *abc* and *def*, and the two end journals are forged in line. Then, instead of cutting out additional V pieces, as shown in Fig. 153, the slab is taken to the machine shop and a rectangular piece *ghik*, equal in width to the space between the cranks, is slotted out from the middle of the slab, Fig. 155. The forging is then

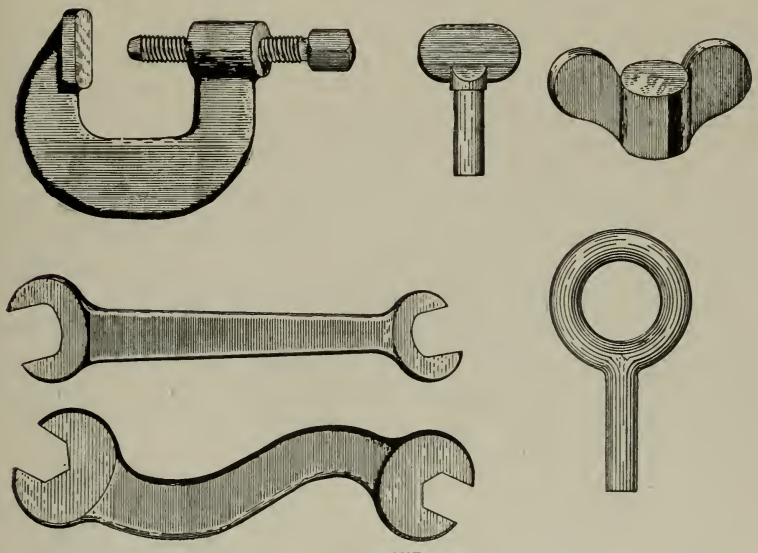


Fig. 157.

placed on the lathe and the middle journal turned. It is then heated, taken to the press or hammer plant, held as shown in Fig. 156, and twisted through an angle of 180° by means of a ratchet formed by attaching a dog to the chuck. The dog is usually worked by hydraulic power. From this stage the rest of the process is all machine work.

Drop Forgings.—Generally all forgings made between two dies, recessed to the finished shape desired, are known as *drop forgings*, whether made by a drop press, steam hammer, or hydraulic press. Each die is recessed in its face, so that when they are brought to-

gether the cavity in the dies is the exact form of the required forging. The upper die is secured by suitable fastenings to the hammer, while the lower or anvil die is secured to the anvil bed. The forging is made by placing the heated stock or *blank* in the lower die and the hammer then brought down upon it, the ragged edges or *fins* are afterwards chipped off the forging. This operation is used when objects exactly alike in form and dimensions are required in large quantities, as by this method they can be forged much more quickly and at a considerable reduction in cost. Sometimes two or more sets of cavities are made in the same die, one set being used for roughing the stock to shape and another set for finishing.

The dies are usually made of steel, if they are to be used extensively, and if intended for good finished products are worked out in the machine shop, and are rather costly. Cheaper dies may be made of massive cast iron, and a considerable amount of rough work can be satisfactorily performed with them, provided it is not too heavy. Some of the numerous objects that can be profitably made by the drop-forging process are shown in Fig. 157.

Hollow-Steel Forgings.—There are two ways of making a forging hollow; one is by boring out the center and then tempering the material, while the second method of getting rid of the center of large forgings is to forge them hollow; this latter method is superior for several reasons:

The walls of hollow forgings are comparatively thin, hence the metal must be without flaw or defect, homogeneous and thoroughly worked. In order to work the metal to get strength and toughness, the ingot should be at least twice the diameter of the finished forging, Krupp uses three times the diameter. Ingots for large shafts are liable to contain blow-holes, cavities, and segregation, the locality of the last cooling, viz., the central and upper portions, are where these defects are likely to occur, hence the ingot is made about 25 percent longer than necessary. The defects, segregation, etc., collecting naturally at the top and in the center of the ingot, the former is cut off and the center of the remaining part bored out, thus eliminating the defects and leaving a piece of steel as sound and homogeneous as can be practically obtained.

After the hole has been bored in the ingot, it must be re-heated,

and considerable care must be exercised in the operation; the heat should penetrate it slowly and uniformly. With a hollow ingot the heat affects equally the exterior and the center, and the two expanding together, cracking is less likely to occur than with a solid ingot. After re-heating the ingot, a mandrel of a size to fit loosely is inserted into the center hole, taken to a hydraulic forging press, and the metal forced down and out over the mandrel. By this means an internal anvil is practically inserted into the forging and there is less than one-half the metal to work than if the piece was solid. A hydraulic press is preferable to a hammer for large forgings, for the pressure in shaping a body of steel should be sufficient in amount, and maintained long enough, to penetrate to the center and cause flowing throughout the mass. With the high velocity of impact of the hammer, the metal does not have time to flow, thus causing internal strains and cracks.

In the process of working down the metal from the greater to the required diameter, and extending it in length, the metal will not flow if too cold and injury would result, hence re-heating from time to time during the operation is necessary. This frequent re-heating, wholly or in part, together with the manipulation, sets up various strains in the forging, necessitating a further process of annealing, by heating the forging slowly to the required temperature, and allowing both furnace and forging to cool down slowly together. This annealing not only removes these *forging strains,* which develop into weakness in service, but gives the metal a finer grain and increases toughness.

Oil Tempering.—This consists in heating the forging to a temperature, determined by the use to which the forging is to be placed, then plunging it into a bath of oil, and this is followed by a mild annealing to remove any surface strains that may have been occasioned by the rapid cooling. For instance, in oil tempering a section of shafting, it is suspended by one end in a vertical furnace, one end of which is hinged for the whole height of furnace. A red heat is given the shaft by oil burners set out at intervals around and up the surface; the side of the furnace is then swung open and the shaft carried out by an overhead crane, over the oil pit, when it is rapidly lowered until it is submerged. Cotton-seed oil is used in the pit, kept in circulation by an oil pump, and kept cool by

water circulation in the surrounding jacket. When cold the shaft is lifted out, annealed, and again when cold is ready for the final machining.

This double treatment, in addition to hardening the material and breaking up the crystalline structure due to forging, modifies the physical properties of the steel by increasing the elastic limit and toughness.

This steel is embraced under the head of Class A in U. S. Naval Steel Specifications, and has a tensile strength of from 80,000 to 90,000 pounds per square inch, with an elastic limit of from 45,000 to 55,000 pounds.

By introducing about 3 percent of nickel into the composition a fine granular or amorphous condition is obtained in the forgings, and the highest quality of steel attained, known in Naval Steel Specifications as High-Grade Steel, with minimum requirements of 95,000 pounds tensile strength and 65,000 minimum elastic limit.

Fluid Compression Steel.—The defects due to blow-holes, piping, and segregation are greatly modified by the process of compression under a hydraulic press when fluid. In the process of fluid compression, the ingot mould varies from two to six feet in diameter and is built up in sections to any desired height. After the mould is filled, it is placed on a platen and run underneath a hydraulic press, where a pressure of not less than 15 or 20 tons per square inch is exerted. Under the great pressure, the air entrained in the pouring is forced out through joints in the mould, where vents have been left, and the gases likely to form in the cooling are prevented from generating.

The Whitworth press is shown in Fig. 158. *DD* are four pillars guiding and supporting the main crosshead *B*, the latter being raised and lowered by an overhead hydraulic cylinder *E* with its plunger *F*, crosshead *G*, and side rods *HH*, coupled at their extremities to *A*. This movable crosshead can be secured and locked in any position by the nuts *KK*. The handles *Q* connect with mechanism for locking and unlocking. *T* is a plunger fitting into the mould, and against which the steel in the mould is forced by the main compressing cylinder, with its plunger *L*. *J* is a platen on a carriage, on which the ingot mould rests. *V* is an apparatus employed to record the movement of the pressing ram, and indicates

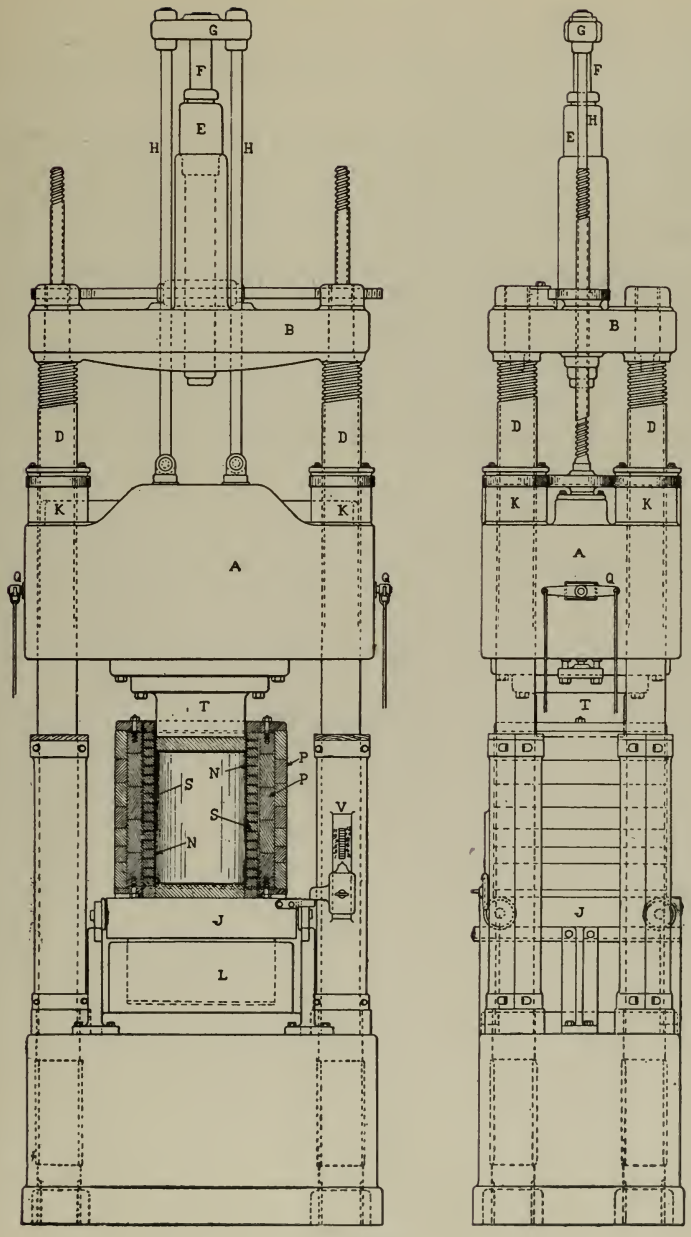


FIG. 158.

the reduction of length while the ingot undergoes pressure. *PP* are steel jackets for the mould. *SS* perforated iron lagging, and *NN* the inner sand lining.

Operation.—The crosshead is lowered until the plunger *T* sets into the mould, and comes in contact with the upper surface of the fluid steel, completely closing the mould, and then the crosshead is locked in position. The plunger *L*, on which the mould and platen rests, is lifted by hydraulic pressure, forcing the steel against the rigidly fixed crosshead. During compression there is a great evolution of gas and flame. After the maximum compression, which varies with the size of the ingot, the pressure is reduced to about 1500 pounds per square inch and maintained until the metal is sufficiently cooled to avoid any further contraction.

CHAPTER VII.

THE MACHINE SHOP.

In the process of the manufacture of engineering material for structural work and machinery, the rough castings and forgings having been produced by the pattern-maker, moulder, and the work at the forge and rolling mills, they are now finished up by machine tools and hand work, preparatory to going on the *erecting floor,* where they are assembled and fitted to form the completed structure.

The machine-shop operation is divided into three parts, consisting of *marking off,* in which the outline of the work to be done is accurately laid off, set and marked by lines made durable by light prick punching. The second stage is the *machining,* in which all the superfluous metal is removed by automatic or partially automatic machine tools as closely as possible, leaving only that portion which must be done by hand power in the way of filing, scraping, chiseling, and grinding to a fit or bearing, and to which the general name, *fitting,* is given. From this point the work is sent on to the *erecting shop,* or to an *erecting floor,* in one corner of the machine shop, where the parts are all assembled and finally fitted together. In the case of naval engines, after erection they are then dismantled, removed, and erected in place on the foundation or seatings provided.

Equipment of a Machine Shop.—The installation in a shop depends largely upon the character and quantity of the output of the finished products. When the product is one style of machinery with duplicated work, special machines are designed and the hand work reduced to the minimum, automatic appliances being used wherever possible or practicable. In the machine shop of an engine and ship-building establishment, and in the smaller shops for general work, there are a number of essential machine tools, the number and size of which are governed entirely by the size of the plant. The machines may be classified under the heads of lathes,

planing, shaping and slotting machines, boring and drilling machines, and milling machines. There are many varieties of each of the above general types, and some of the principal machine tools found in a large shop are as follows:

Lathes from 14-inch swing and 5-foot bed up to the largest sizes, gap lathes, turret lathes, monitor or chucking lathes, and turret screw machines. Planing machines of the ordinary form, and open side planers. Shaping machines and slotting machines. Boring mills, both of the horizontal and vertical types. Drilling machines of the upright type, multiple spindle drilling machines, gang drills, radial drilling machines, horizontal drilling machines, and portable drills operated by pneumatic or electric power. Milling machines, cutters, and grinding machines. Cold iron and steel sawing machines. Tool-grinding wheels and machinery. The number and size of the above tools varies with the requirements, and in addition other special forms are employed to suit special needs. In large shops tool grinding is done in a separate room, equipped with the different tool-grinding machinery, grind stones, emery grinders, etc.

Vise Work—Bench Work.—Work in this class is done by workmen skilled in the use of the hammer, chisel, and file, and called *fitters* or *bench machinists.* A machine shop is well equipped with vise benches and vises, and the hand tools used by the bench machinist or fitter comprise measuring instruments, gages, calipers, etc., of various kinds, hammers, chisels, files, scrapers, taps, dies, screw gages, steel squares, screw and Stillson wrenches, and a variety of other hand tools used in the work of fitting up machinery.

Erectors are employed in assembling and putting together the parts of mechanism previously machined and fitted, and for large engine works, where there is not much duplication, it requires men not only skilled at the bench, but of experience in the adaptation, correction, and adjustment of the relative position of the parts of the mechanism to be assembled.

The tools used by the erecting gang, in addition to many used by the fitter, consist of lifting tackle, such as differential hoisting tackle, etc., ratchet drills and portable drills, screw and hydraulic jacks, lead hammers for use on finished work, hack saws, reamers, etc.

Marking Off.—When the work is received from the outside shops it is placed on the marking-off table, measured all over, and then, in accordance with the drawings furnished, the outline of the finished work is scribed off and the centers marked. In cored castings, such as a steam cylinder, a strip of wood, or two strips at right angles, are fitted across the bore and the center marked, from which the circumference of the finished bore, flanges, bolt centers, etc., are laid off and cord passed through the cylinder for the measurements from the axial line of the cylinder bore. Where wooden plugs or battens are used in cavities for obtaining the center, pieces of tin are inserted at the approximate centers to prevent the mark enlarging and becoming inaccurate from frequent use.

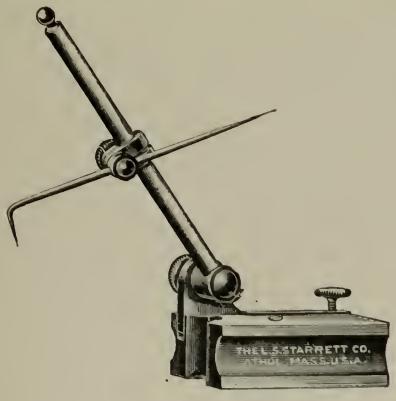


FIG. 159.

The marking-off table varies in size from 4 feet to 12 feet, according to the size of the shop, the top planed true and scraped, the sides at right angles to the top and to each other, while the bottom is ribbed for stiffness, similar to a surface plate. The table is then set level and supported so as to remain firm under the loads placed upon it.

The tools used by the marker-off on this table consists of *V blocks,* to support cylindrical work, such as shafts; *cubical blocks,* made true in every direction and used for building up, for instance, to obtain greater height for a scribing block. The *scribing block,* Fig. 159, consists of a rod fitted to a solid base, which has been truly scraped on the bottom. A head slides upon the rod and has

connected to it a steel scriber with one point straight and the other curved. The head can be locked at any point on the rod by the set screw, while the scriber can be secured at an angle, or with a greater or less swing by another screw. The *hand scriber* is identical with the scriber mentioned above except that both points are straight, and its use to the machinist is about the same as that of the pencil to the draftsman. *Compasses* of several sizes and *trammels* are used for striking out arcs, and laying off distances from center marks. *Steel rules* accurately divided to 64th and also in accordance with the decimal system. *Steel squares,* Fig. 160, large and small. *Calipers* are used for both inside and outside measurement. Finally, a *spirit level,* or a plumb-bob, and prick punches and center punch, this latter being used for marking the main

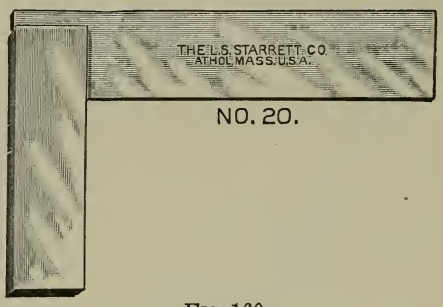


FIG. 160.

centers while the former is used to render the scribed lines more permanent by pricking a series of small punch marks on the metal.

For an example of the method and procedure in *marking off* a piece of work, take the triple-expansion engine now under construction in the machine shop of the Department of Engineering, $8\frac{3}{4}''$ x $13''$ x $22''$ x $12''$ stroke, and mark off the high-pressure cylinder.

Referring to the three views of this cylinder, Fig. 161, the casting, after being pickled, cleaned, etc., is placed on the surface table, and a preliminary measurement of all parts taken to ascertain if there is metal sufficient, due to shifting of the cores, etc., to turn out the finished machine. It will be noted that the cylinder is fitted for a piston valve *A;* has a bottom cylinder head cast with the cylinder barrel, together with the stuffing-box opening *B;* is fitted with the lugs *CC* for supporting engine columns, while the

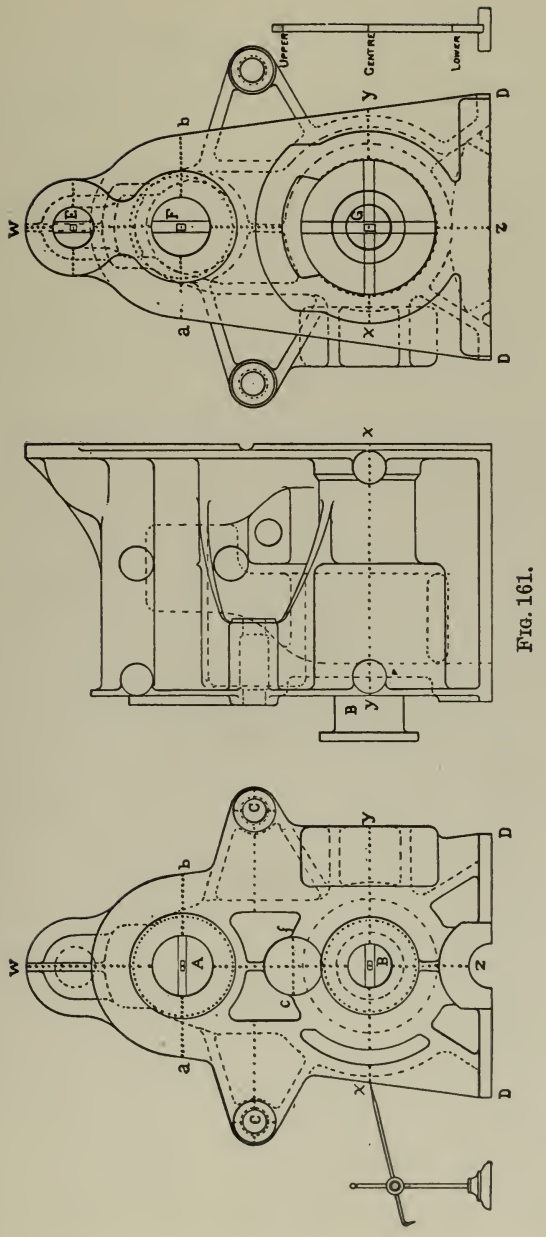


FIG. 161.

face *DD* is bolted to the steam chest of the succeeding intermediate cylinder.

On the top we have the steam opening *E*, valve-chest opening *F*, cylinder bore *G*, and flange connection *DD* to intermediate valve chest.

Place the cylinder with the flange *DD* resting on the surface table, block it up temporarily as nearly level as possible, and fit cross pieces of wood with a small piece of tin inserted in the approximate center of each, of all the cored openings, such as the piston rod stuffing box, cylinder bore, valve-chest bore, etc. Obtain the center line or axis of the cylinder bore. To do this, make a batten of wood, lay it on the table with the upright, square with the table. First, with a surface block, obtain the transverse center line for the top end, by measuring the distance of the outside of the cylinder barrel from the surface table, measuring near the flange, and transferring it by means of the surface block to the wooden upright. Repeat this operation for the lower part of the barrel. Divide these marks equally and we obtain the height of the preliminary center for the top end. Repeat this at the stuffing box or bottom end of the cylinder, using the outside of the stuffing-box neck for measurements, and compare these two tentative center lines to see if the casting has warped or shifted any of its parts of the pattern or cores. If adjustments become necessary, it is done by blocking up the surface *DD* at the ends or sides desired, repeating the surface-block measurements until a proper mean is obtained. Care must be taken in blocking not to throw the flanges *DD* too much out of square, as to make it impossible to face it up true to the center line of cylinder on account of insufficient metal. This should also be looked after in the case of all the flanges, such as cylinder and stuffing-box flanges. Having determined the height distances, set the surface black and scribe a line *xy* entirely around the outside surface of the cylinder.

Maintain the cylinder in the same position on the surface table and proceed with the other lines. From the drawings ascertain the distance of the axis of the piston valve chest from the axis of the cylinder, test this on the top and bottom flanges, try an approximate center, and test for thickness of metal in the valve-chest bore for both ends, to ascertain if sufficient metal is available for boring,

then scribe the line *ab* top and bottom. Next measure the distance of the center of the columns and scribe the line *CC* completely across the bottom of the casting with the surface block set to the prescribed distance. Similarly and with the proper distance from *xy*, scribe the line *cf* across the lug shown for the cylinder drain.

Now turn the cylinder casting over on the surface table at right angles to its former position, block it up so that the horizontal lines previously drawn now stand perpendicular to the surface of the surface table, and the ends also square with the table. This is accomplished by large steel squares. Then, as explained before, test materials for centers of cylinder bore and make a preliminary mark on the lines *xy*, at the top and bottom of the cylinder. Similarly try the preliminary marks for the center of the valve-chest bore. Try the scriber block on the two centers thus found, and if any difference is perceptible, adjust it between the two and then, with the new-found height, scribe the line *wz* across cylinder and valve chest with the surface block set to this height, and at both top and bottom ends. The intersection with the lines previously drawn with the cylinder in the first position, gives us the various centers required, such as for the axis of the cylinder and valve-chest bore and cylinder drain. Lay off from the drawings the distance of the centers of the columns *CC* from the line *wz* and we obtain and mark the centers on the lugs to which the columns are secured.

With dividers and radius taken from the drawing, and with the center already obtained, describe the circumference of the cylinder bore on the cylinder flange. In like manner describe circles for the bore of the piston rod stuffing box, the valve-chest bore, or a concentric reference circle, cylinder drain opening, column lugs, and to make them permanent and visible prick-point the circles and all the lines of reference, as shown in Fig. 161.

We are now ready to go to the boring mill and work is transported to the boring-mill platen, and adjusted so that the axis of the cylinder, as marked, coincides with the axis of the boring bar. Care must be taken in clamping down, that the cylinder is in no way sprung or warped. The cylinder, stuffing box, and counterbore are now bored out, and the cylinder flanges and the face of the stuffing box faced off.

Without disturbing the setting, the platen of the boring mill is

lowered and the boring bar set to the axis of the valve chest, the valve chest bored out, and flanges faced.

The cylinder is then transferred to the planer and the flange *DD* faced off to size, using as a reference line the axis of the cylinder and marks previously obtained.

With the leading lines thus laid off, the cylinder is finished up in accordance with the drawings.

Measurements are made by a *rule* or by a *gage;* for line measures a graduated steel rule of good workmanship and quality is reliable. In transfering a measurement by calipers, compasses, or trammels from a rule, or in measuring the length of a rod, the operation is governed by the sense of sight. In the case of boring a hole of a given diameter, such as one in a wheel or pulley to fit accurately a given shaft, a cylindrical gage of the exact diameter of the shaft is used, or a pointed trammel whose length is exactly that of the diameter of the shaft, the operation is here governed by the sense of touch.

FIG. 162.

Standard steel rules, Fig. 162, are made in different lengths and graduated on the four edges into sub-divisions of 8ths, 12ths, 10ths, and millimeters.

Calipers are of two kinds, one to obtain the outside diameters of cylindrical surfaces and called *outside calipers,* and the other known as *inside calipers* for obtaining the inside diameter of a cylinder or cavity. These instruments are used in transferring measurements from one piece of work to another. There are many forms of calipers in the market, but the most general types, the outside, inside, spring calipers, and spring dividers, are shown in Figs. 163, 164, 165, and 166. A method of locking the joints of calipers so that they may be used inside of chambered cavities, over flanges, etc., the caliper removed and legs replaced without losing the size calipered, is shown in Fig. 167. This operation is accomplished

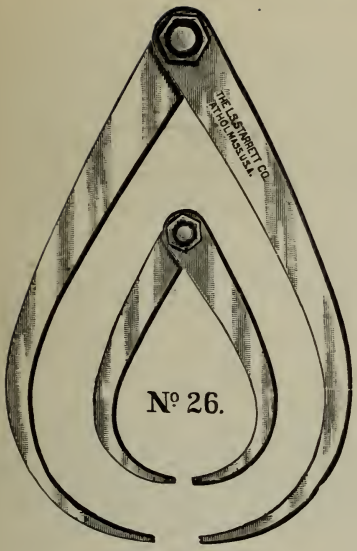


FIG. 163.

FIG. 164.

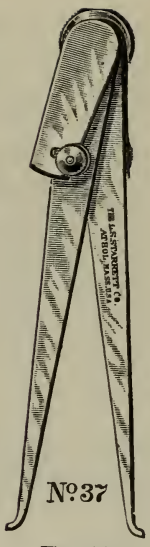


FIG. 167.

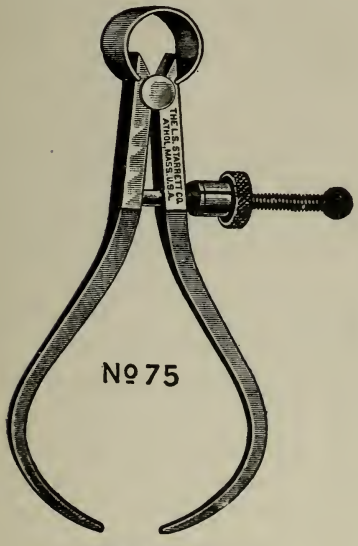


FIG. 165.

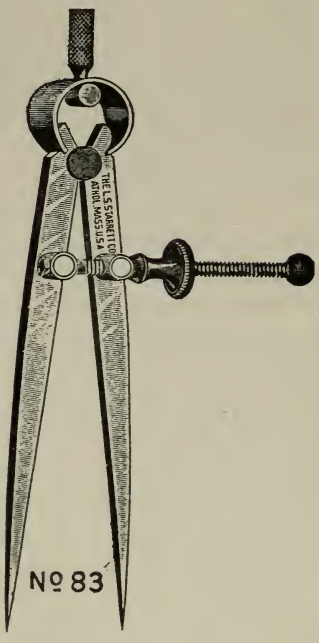


FIG. 166.

by loosening the nut binding one leg to the auxiliary arm and swinging it out or in (while the joint is locked) to clear the obstruction, then moving it back against a stop, where the exact size will then be indicated. In making calipers, they should be well proportioned, made of steel, tempered, and the joint carefully fitted so that the legs will open and close with a uniform steady movement.

Micrometer calipers belong to a class of calipers which can be used not only for transferring dimension from one object to another, but contains a scale by which the length of the object is also recorded. They are made in different sizes and graduated to read either in thousands or ten-thousandths of an inch.

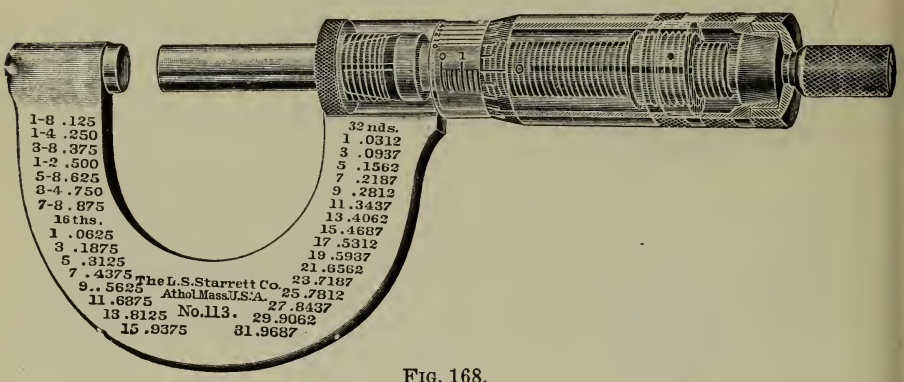


FIG. 168.

The chief mechanical principle, Figs. 168 and 169, in the construction is that of a screw free to move in a fixed nut. The backward movement of the screw furnishes an opening for the work to be measured, and the size of the opening is indicated by the graduations.

The pitch of the screw is forty threads to the inch. The graduations on the sleeve *D* in a line parallel to the axis of the screw is forty to the inch, and as these graduations conform to the pitch of the screw, each division represents the longitudinal distance travelled by the screw in one rotation, or the caliper has been opened 1/40 of an inch. The beveled edge of the thimble *E* is graduated into 25 parts on its circumference and each division, when passing the line of graduation on the sleeve, indicates that the screw

has made 1/25 of a revolution and the opening of the caliper has been increased by 1/25 of 1/40 or 1/1000 of an inch. When the end of the measuring point *C* and the anvil *B* come in contact, the zero points on the sleeve and the thimble should coincide.

To obtain a reading to ten-thousandths of an inch, a vernier is applied to the sleeve. consists of ten parallel lines cut on the sleeve

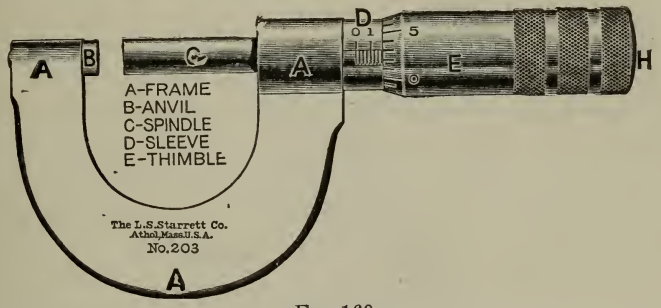


FIG. 169.

and occupying the same distance as nine of the twenty-five divisions on the thimble, see Fig. 169a. Hence, each of these ten parallel spaces is one-tenth shorter than the divisions on the thimble, and we obtain for one division on vernier an opening in the caliper equal to $1/10 \times 1/25 \times 1/40 = 1/10{,}000$ of an inch.

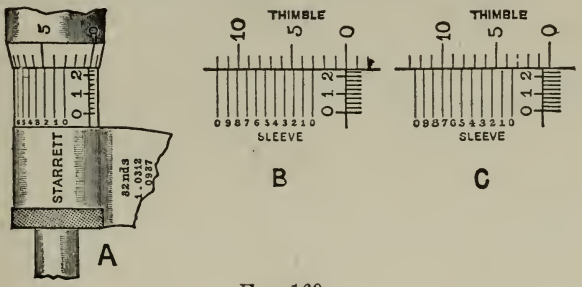


FIG. 169a.

The vernier caliper is another example of a machine shop measuring instrument in the form of a beam caliper, with a graduated scale on the side of the beam, and sub-divisions on the vernier on the underneath sliding jaw. The sliding jaw is given its final or precision adjustments by means of a small nut and screw on the secondary slide.

The action of the instrument, Fig. 170, is as follows: On the beam of the instrument is a line of inches numbered 0, 1, 2, etc., each divided into ten parts and each tenth into five parts, making fifty divisions to the inch. On the vernier of the sliding jaw there are twenty divisions, spaced so that they cover exactly nineteen divisions on the beam scale, consequently each division on the vernier differs in length from a scale division by $1/20 \times 1/50 = 1/1000$ of an inch, that is, if the sliding jaw of the caliper is pushed up to the other, so that the zero of the vernier coincides with the zero of the beam scale, the next two lines differ from each other by one-thousandth of an inch, and this difference will increase the same amount for each division until at the point twenty on the vernier they again coincide. In the figure the zero of the vernier stands at

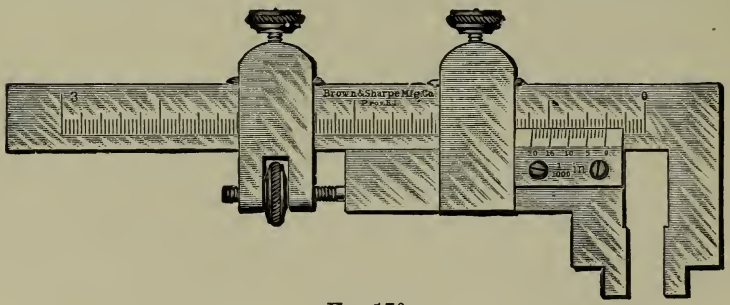


FIG. 170.

.2 inch; if the sliding jaw is now moved out a short distance towards the next division on the beam scale, examine the vernier divisions until one is found to be in line with one on the beam divisions. Assuming this occurs at the vernier division ten and its coincident beam scale line is .4 inch, then the jaws have been moved further apart by $10/20 \times 1/50 = 1/100$ of an inch, and the two jars are now apart $.2 + .01 = .21$. Or, briefly, set the caliper to the work to be measured, then count upon the vernier the number of divisions until one is found which coincides with one on the beam scale, which will be the number of thousandths to be added to the distance read off on the beam scale.

Gages.—In the manufacture of duplicate pieces where interchangeability is an important feature, it is necessary to have gages whereby the degree of tightness or looseness may be kept within the

assigned limits, and uniformity of product assured. For every-day work in the machine shop, convenient forms are shown in Figs. 171 and 172. In the external limit gage shown, openings are pro-

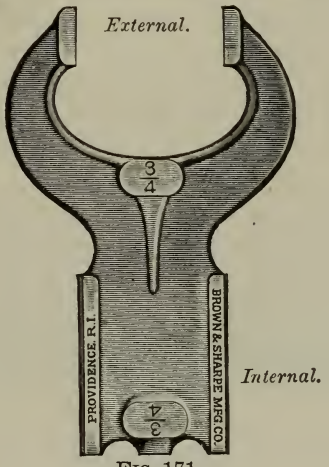


FIG. 171.

vided at each end, giving the maximum and minimum limits. These gages should be made of good steel and properly hardened.

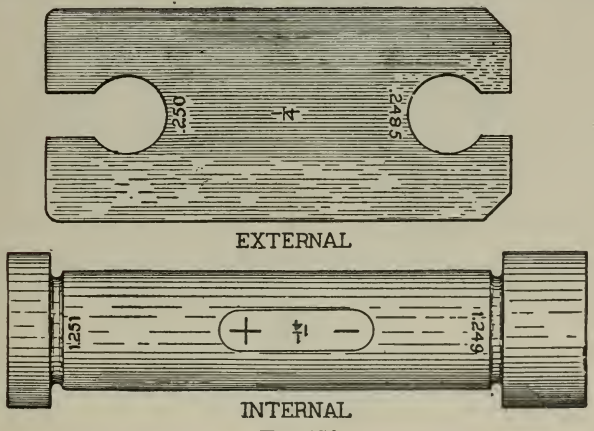


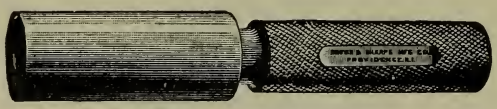
FIG. 172.

Internal limit gages, Fig. 172, are used in a similar manner, with accurately finished maximum and minimum sized plugs taking the place of openings in the outside gage.

Standard Cylindrical Gages.—In Fig. 173 is shown a plug and ring gage. They are made in the most careful manner and furnished in sets from one-quarter inch to two inches, varying by sixteenths of an inch. With these gages a hole may be bored or a rod turned, tested and gaged to a degree of accuracy that will ensure a perfect fit without trial.

Wire and Sheet Metal Gages.—The gages used to indicate the size of wire, sheet metal, machine metal, machine screws, drills, etc., are on such different systems and the corresponding numbers to indicate the same dimensions differ so from each other, that confu-

Internal.



External.

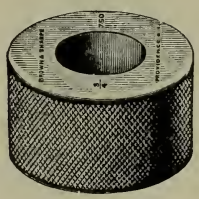


FIG. 173.

sion will result unless the gage is specifically mentioned. The variation in the different standard gages used in the United States can be seen from a comparison of a few numbers taken from the different gages enumerated below:

Number on Gage.	American or Brown & Sharpe.	Birmingham, B. W. G.	Imperial.	Stubb's Steel.	U. S. Standard for Plate.
0	.32486	.34	.324	...	.3125
1	.2893	.3	.300	.227	.28125
2	.25763	.284	.276	.219	.265625
3	.22942	.259	.252	.212	.25

Of the above the ones in principal use for U. S. Naval work are the American, the B. W. G., and the U. S. Standard Plate Gage. In the American gage the dimensions increase in regular geometrical progression, and are found by multiplying the preceding dimen-

sion by a decimal constant .890522. The Birmingham Wire Gage is much used, both for plate metal, rods, and wire. The United

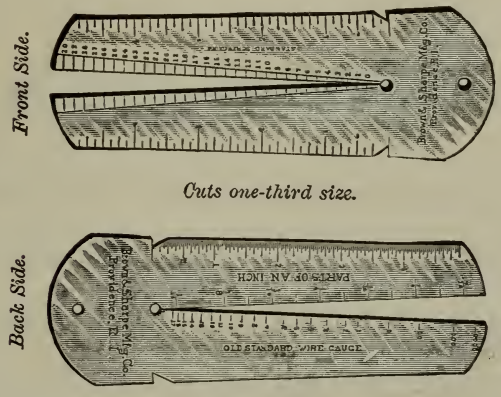


FIG. 174.

States Standard was adopted by Act of Congress, 1893, for iron and steel plates, and in all U. S. Naval work where steel plates are ordered by gage, this gage must be used.

FIG. 175.

The above gages are made in two forms, the angular and the notched. With the angular gage the material to be measured is passed in the notch until it touches both sides, when the reading

opposite gives the number. With the notched gage, the material should just pass through one of the notches, the number of which is found opposite. The angular and notched gages are illustrated in Figs. 174 and 175.

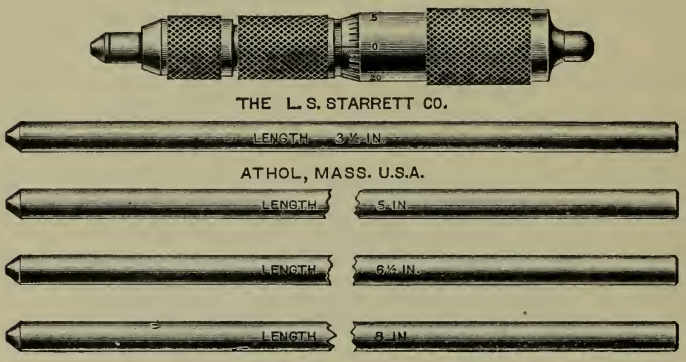
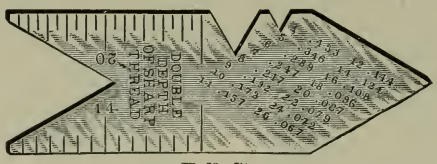


FIG. 176.

Fig. 176 shows a series of inside micrometer gages for making internal measurements of cylinders, rings, setting calipers, comparing gages, and work of a similar character.

The above are a few of the principal calipers, gages, and indicators in use in shop practice. Various modifications will be seen in the course of the practical drills in the Department of Engineer-



Full Size.

FIG. 177.

ing, among which may be mentioned, measuring instruments for screw threads, drill gages, center gages for gaging lathe and other machine centers when grinding them; thickness gages, consisting of a number of thin steel leaves arranged like a pocket knife, the thickness of the blades varying by thousandths of an inch, various combination steel squares, rules, inclinometers, depth gages, center testers and protractors.

Center Gage.—This tool is used for gaging centers for lathes and other machine tools when it becomes necessary to turn or grind them, and is also used in grinding and setting screw-threading tools,

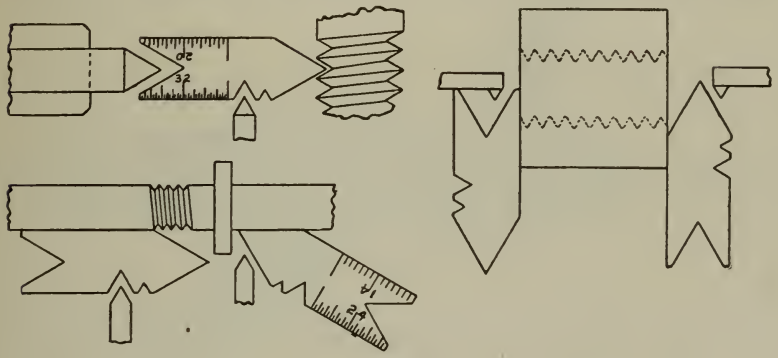


FIG. 178.

setting out, squaring work, etc. The gage is shown in Fig. 177, while in Fig. 178 are illustrations showing some of the uses to which this tool may be applied. The angle of the sides is 60°, and

FIG. 179.

the table at one end is for the purpose of ascertaining the proper size drill for use in tapping full V threads. In this table the whole numbers represent threads per inch, while the decimal numbers opposite give the double depth of V threads of the corre-

sponding pitches. For instance, it is desired to know the size hole to be drilled for a one-inch tap with eight threads to the inch, we

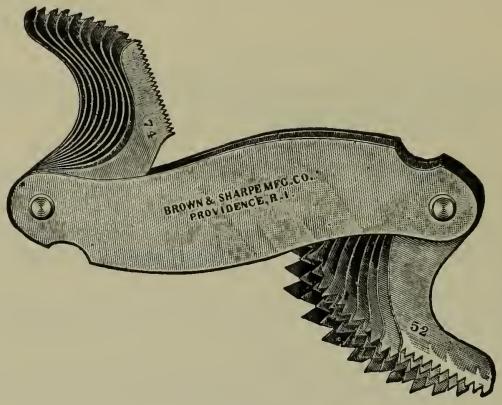


FIG. 180.

have from the table, the double depth corresponding to eight threads is .217 inches, leaving the size hole to be drilled $1 - .217 = .783$ inches, or $\frac{13}{16}$ inches approximately.

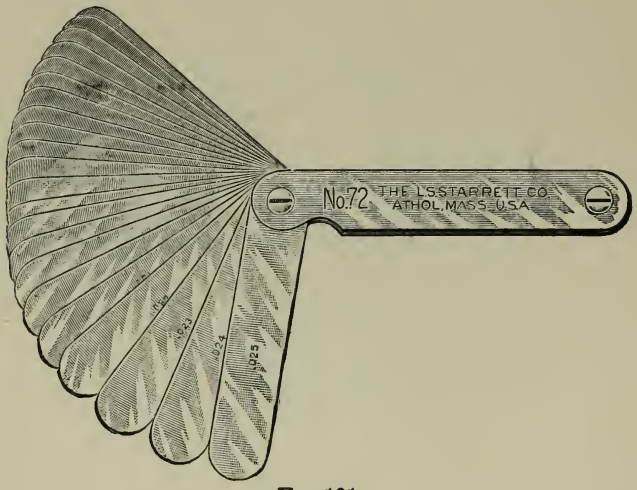


FIG. 181.

For grinding screw-threading tools, a *screw-thread gage* is used, of the form shown in Fig. 179. As illustrated, the notches, with

the exception of one, are all made for gaging U. S. Standard threads, being flattened at the root by the amount the top of the thread is cut off in the various pitches, according to the standard. There is a single 60° V notch on this gage for the purpose of gaging all V threads.

The *screw-pitch gage,* Fig. 180, is a compact tool with a number of blades folding up into a handle with each blade containing sev-

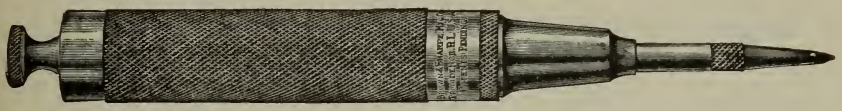


Fig. 182.

eral teeth corresponding to that marked on the blade. It is used on a screw thread to determine at once the exact pitch without the tedious and unreliable method of counting the number of threads per inch over a rule.

The *thickness gage,* Fig. 181, is similar in appearance to the pitch gage and consists of a number of thin steel blades, each marked and varying in thickness by the thousandths of an inch. This tool can be utilized for numerous purposes in the machine shop and on the erecting floor. The automatic center punch is shown in Fig. 182.

CHAPTER VIII.

VISE WORK AND TOOLS.

Hammer and Chisel.—Machinist's hammers weigh from one to one and one-half pounds, are of a good grade of steel, tempered both at the head and pene, leaving the center soft, and are made in the three shapes as shown in Fig. 183. These different shapes are known as the ball pene *A*, straight pene *B*, and cross pene *C*. The pene is used for riveting purposes. The handle is of straight grained hickory firmly secured in the eye of the hammer, and in use should be grasped near the end, and with an easy arm movement the hammer should be swung through a vertical plane.

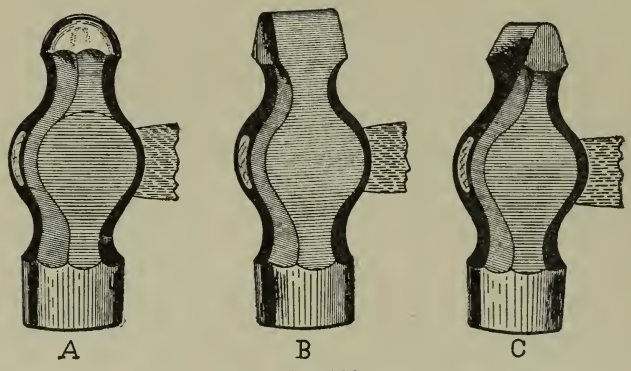


FIG. 183.

There are three leading varieties of *cold chisels:* The *cape chisel,* Fig. 185, is used for roughing out work or channeling for the flat chisel to follow. The *flat chisel,* Fig. 184, is employed to face up the surfaces previous to filing, while the *half-round* chisel, Fig. 186, is for the purpose of chipping out grooves, or for drawing a center punch mark or counter sink which has commenced to run out of

truth in drilling, by chipping to one side and drawing the center away, after which the drill is again inserted. Chisels are usually made of $\frac{3}{4}$ inch octagon steel and the flat faces dressed to about three inches from the cutting edge. The facets are ground to an angle depending upon the material to be worked upon; for soft metal, such as brass, the faces make an angle of about 45° with each other, while for steel the angle is increased to 60° or 70°.

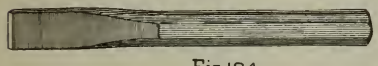


Fig. 184

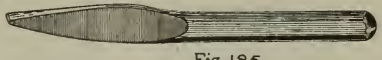


Fig. 185

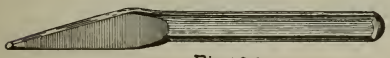


Fig. 186

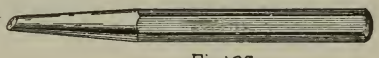


Fig. 187

Fig. 188.

The chisel should be held well up near the head with the full hand, knuckles up, and the eye should follow the cutting edge of the chisel and not the hammer head.

The Vise.—There are three kinds of vises, hand, bench, and machine vises. Bench vises, Fig. 189, are usually parallel vises and

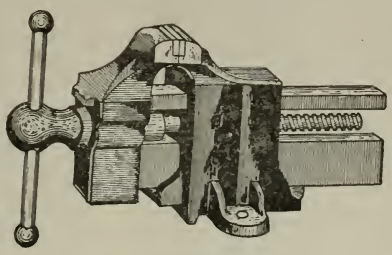


Fig. 189.

may have either a simple screw arrangement for gripping, or some method of rapid adjustment. The machine vise is used on the tables of milling, shaping, and drilling machines, for holding down the work instead of clamping it directly to the tables, thus making the setting easier and with a saving of time.

Files and Filing.—Files are made of high-grade crucible steel, forged to shape, ground, the teeth cut, and then carefully tempered. The length of file, as stated commercially, is the distance between its *heel* (or where the *tang* begins) and the point or end opposite;

PLATE A

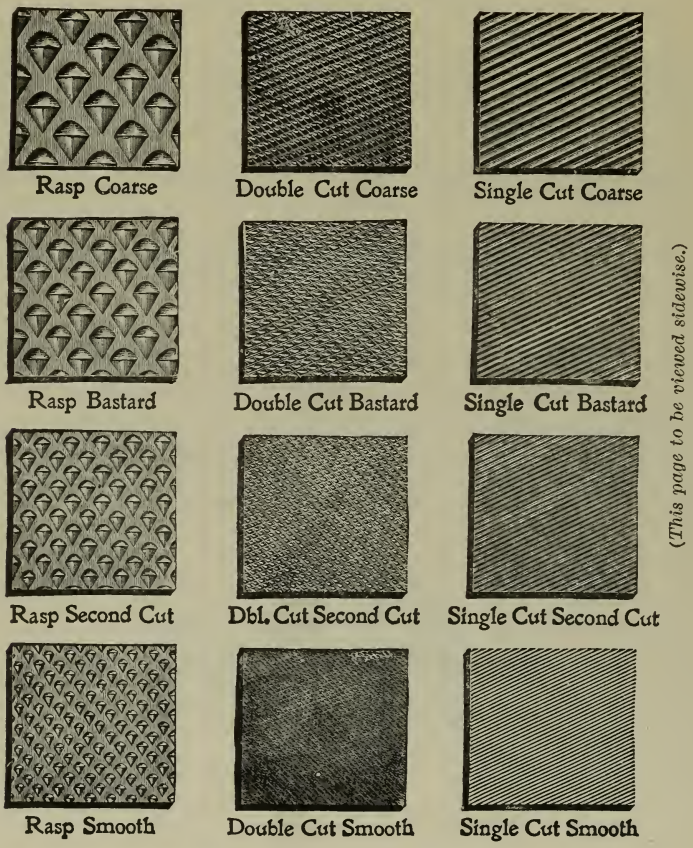


FIG. 190.

the tang is never included in the length. They are divided according to the form of their cross-sections into three classes, *quadrangular* sections, *circular* sections, and *triangular* sections. They are also again divided with reference to the *character* of the teeth, into

single cut or *float files, double cut* and *rasp cut;* and with reference to the *coarseness* of the teeth into *rough, coarse, bastard, second cut,* and *dead smooth.* Both of these features are illustrated in Fig. 190. The coarse and bastard cuts are used upon the heavier class of work, while the second cut and smooth are used for finer grades of work, and for finishing work commenced with the coarse and bastard.

The single cut has its surface covered with rows of parallel chisel cuts across its face and oblique to the length of the file. The double cut has two courses of chisel cuts crossing each other, the second course being usually finer than the first. In the rasp cut the teeth are disconnected from each other and the teeth made by raising up small portion of the surface with a punch.

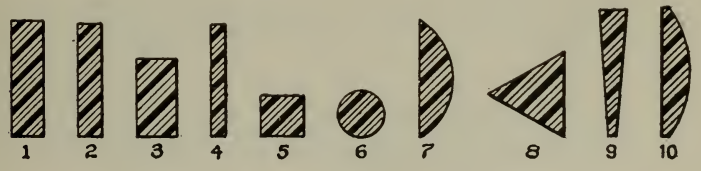


Fig. 191.

In Fig. 191 is shown the sections of a few of the most commonly used files: (1) Flat file, tapered, double cut; (2) mill file, tapered, single cut; (3) pillar file, parallel with taper thickness, double cut; (4) warding file, much tapered in width, double cut, and much used by jewelers, machinists, and blacksmiths; (5) square files, tapered, double cut; (6) round files, tapered, usually bastard cut; (7) half-round files, tapered, double cut; (8) three square files, tapered, double cut; (9) knife file, tapered, double cut; (10) cabinet file, tapered, double cut, wider and thinner than the half-round. *Safe-edge* files are those with one edge left smooth in order that a surface not intended to be filed may be protected.

True filing requires considerable skill; the manner of holding the file is of importance, while the tendency to produce a convex surface is always present. The cutting is done on the forward stroke, hence full pressure should be exerted, while on the return stroke the pressure is reduced. During filing the surface should be frequently tested with a straight-edge and finally by a hand-

surface plate slightly smeared with red lead. Frequently brush the file to remove small particles in the teeth and prevent scratching. Rubbing the file with chalk will produce the same result, as it will prevent the filed particles from adhering. The skin of a casting is generally removed by chipping before filing, to prevent

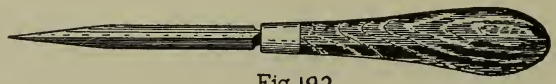


Fig. 192.

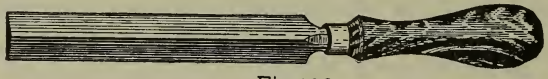


Fig. 193.

Fig. 194

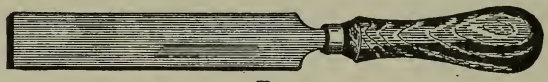


Fig. 195.

the teeth from being dulled by the hard surface. *Draw-filing* is the finishing of narrow surfaces not to be scraped, by taking the ends of the file in both hands and drawing the file along the length of the work.

Scrapers.—Scrapers are made use of by the machinist to make perfect contact between two surfaces of metal. The surfaces are

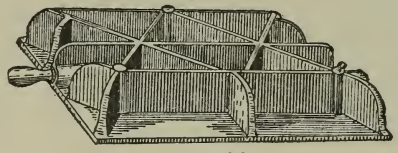


FIG. 196.

first carefully machined or filed to as true a surface as possible, then a *surface plate,* Fig. 196, lightly smeared with red lead, mixed with oil, is placed upon the surface, when the red lead will adhere to the high spots. These patches are scraped down and the plate again applied and the high spots found, again scraped. This is

repeated until finally the surface plate obtains contact over the entire surface of the work. The different shapes employed for scrapers are shown in Figs. 192 to 195.

To Make a Surface Plate.—If there is a standard surface plate in the shop and a new one required, it is made directly from the standard by the method shown above. In the absence of a standard plate a new one may be originated as follows: Take three plates *A*-*B*-*C*, plane them truly and smooth file them to remove tool

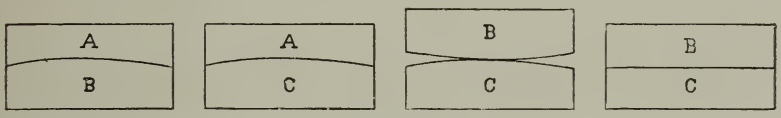


Fig. 197.

marks. Starting with *A* as a standard, fit *B* and *C* to it by scraping and the color-patch method, then test *B* and *C* with each other and any irregularity in *A* will be reproduced in both *B* and *C*. For instance, a concavity on the surface of *A* will result in a convexity in *B* and *C*, and on placing these surfaces together the error is shown to an exaggerated degree in Fig. 197. Now scrape *B* and *C* to a fit, removing the material equally from both surfaces until they bear accurately on each other. The plate *A* is now fitted to, and made a counterpart of *B*, then it is tested on *C*, and if *B* and *C* when fitted together had been equally reduced, *A* will be found to

Fig. 198.

bear evenly all over the surface of *C*, thus proving all three to be true planes. It is hardly possible that this result will be obtained until this operation has been repeated over and over again, but the same routine should be observed. As the process approaches completion great care is necessary, as any little excess in scraping one part necessitates the reduction of the entire surface to the same extent.

Drills are revolving tools employed to cut holes through metal and may be driven by machine or hand power. They are of two kinds, flat-forged drills and twist drills, the latter now having

largely superseded the former. The flat drill is of the shape shown in Fig. 198, made of round tool steel, flattened and thinned out at the lips and carefully ground to cutting edges as shown. The angle of the cutting edges on each side of the axis of the drill must be equal. The accuracy of the work of this drill is poor and its principal merit, outside of drilling hard steel or chilled castings, is the cheap and easy method of manufacture.

FIG. 199.

Twist Drills.—In Fig. 199 is shown a twist drill, the parts of which are designated as follows: *AA*, the flutes; *BB*, the lips; *C*, the shank, and *D*, the tang. The flutes are cut from prepared round stock in a milling machine, and the depth decreases as the shank is approached, to obtain greater strength. The material used is tool steel, and after finishing they are given a cutting temper.

FIG. 200.

The shanks are made straight or taper, the latter being made in regular sizes and known as the Morse taper, practically five-eighths of an inch to the foot. Drills are held either in adjustable chucks, when the shanks are straight, or by means of sockets made to the standard taper. The drill is removed from the socket and the socket from the machine by a steel drift with a slight taper to enter the socket just above the tang of the drill to force it out.

Reamers.—For accuracy in neat fitting work, holes must be truly round, straight, and uniform, and as a drill can not produce holes to fulfill these conditions, a reamer is run through the hole after drilling.

A reamer, Fig. 200, is a cylindrical cutter tool with grooves running lengthwise and forming cutting edges, and are made either in a tapered form called a *taper reamer* or parallel or *standard reamers,* these latter being used when accurate cylindrical holes

Fig. 201.

are required. Reamers made for hand use are fitted with a square on the end of the shank to receive a tap wrench, while machine reamers have a tapered shank turned to the *Morse gage.* The number of grooves has an appreciable effect upon the accuracy of the work done, those with less than five grooves not being used in work requiring straight and uniform work. *Expanding reamers* are built-up tools in which the cutting edges are capable of adjustment to compensate for wear.

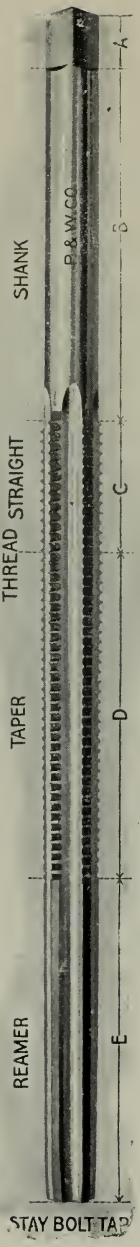


FIG. 202.

Taps and Dies.—Screw threads may be produced in the solid stock by means of a *thread-cutting tool,* or a *screw chaser,* by means of the lathe, or by means of *taps and dies.* The tap produces internal threads, as in a nut, while the die cuts external threads, and both can be employed either by machine or hand power. A set on hand taps is shown in Fig. 201. A set of taps consists of a taper, plug and bottom tap, all cut to the same thread. the tapered form of the taper and plug taps being given by turning down the tops of the threads to a greater or less extent, while in the bottom tap the full thread extends to the point of the tap. All these taps should be used in order, the bottom tap doing but little cutting, and rather to finish up to the standard the threads previously cut.

The hand tap is driven by a double-end wrench, called a *tap wrench,* and after the tap is entered it should be tested by placing a square on the surface, letting the blade enter each flute of the tap, the parallel portion above the threads will at once show if the tap is standing perpendicular. A tap commencing to go in crooked must be corrected while the first two or three threads are being cut, as later there is but little chance of altering its course. When tapping, or in cutting internal threads, a lubricant is necessary with wrought iron, steel, copper, etc., while cast iron and brass are usually tapped without a lubricant.

Taps are made on a screw-cutting lathe having a perfect *feed screw,* by forming the screw threads upon a *blank* and then transferring it to the milling machine, and then fluting it. Afterwards a small relief or clearance angle is removed with a file, and after finishing the tap is hardened and tempered.

Fig. 202 shows a *stay-bolt tap*, and consists of four parts, the reamer portion or lower part, followed by the tapered and parallel threaded portions, and finally by the shank. These taps are as long, as the plates to be stayed are apart, as both plates must be tapped together.

Other taps are *pipe taps* cut for standard pipe gage, combination drill and pipe tap, and *collapsing taps* to permit the tap to be removed without backing out. *Hobs* or *master* taps are used for cutting the thread on dies.

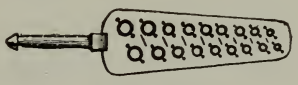


Fig. 203.

Dies.—The screw plate is one of the elementary forms of dies for cutting external threads, and consists of a thin piece of tempered steel, Fig. 203, in which are a number of threaded holes of varying diameter. Cutting edges are formed by the addition of two or more notches to each hole.

For larger work it is necessary to make the cutting action more accurate than with the screw plate and the *stock and die* was intro-

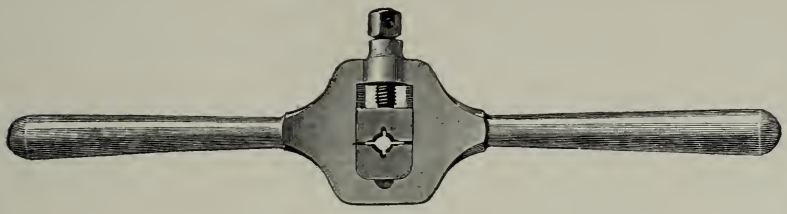


Fig. 204.

duced, Fig. 204, which enable one pair of dies first to trace out the thread lightly and eventually, by bringing the dies more closely together, to cut to the full depth. By making the cavity in the die stock of sufficient length, dies can be easily removed and replaced by others of different sizes. In the use of this tool the dies are separated and a light cut taken to the size desired, the plates are then brought closer together and the motion reversed, and the die brought back. This is repeated until the proper depth of thread is obtained.

In the following types of dies a finished thread is obtained by running the die once over the stock.

The dies illustrated in Fig. 205 are largely used for varied work. The die is inserted in a collar and is adjusted for wear by

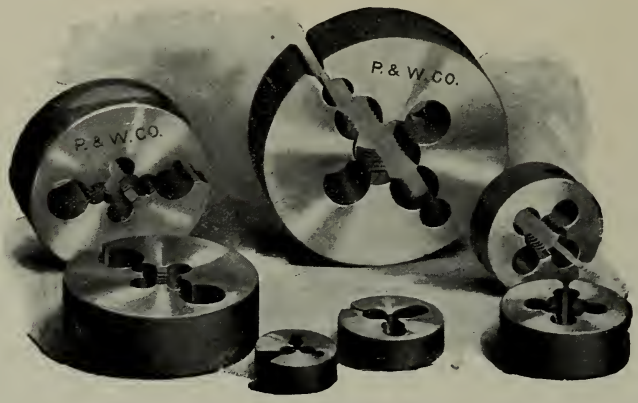


FIG. 205.

means of a small screw passing through the collar and engaging the die, springs it together.

The die shown in Fig. 206 consists of two parts held together by four screws passing through the die stock, Fig. 207, and enter-

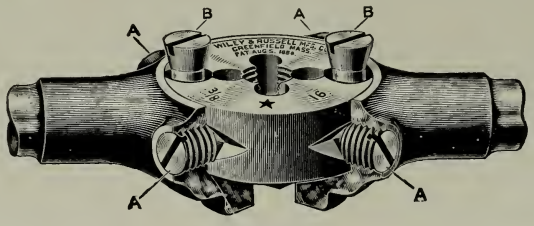


FIG. 206.

FIG. 207.

ing appropriate notches in the die edge. As wear progresses two wedge-shaped (taper head) screws on the face bring the two halves of the die closer together as the cutting edges wear.

Another form of die is the Grant adjustable die, Fig. 208, and consists of four chasers secured in a collet and held by an encir-

FIG. 208.

cling ring. By forcing down the ring the chasers are pushed towards the center, the maximum adjustment being $\frac{1}{32}$ inch.

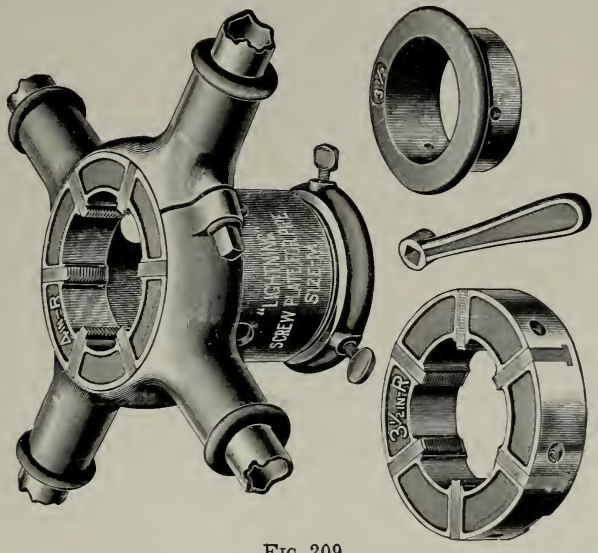


FIG. 209.

Pipe stocks and dies are shown in Fig. 209. Solid machine or bolt dies are made in the same shape.

With the above tools for cutting threads for fastenings, three different kinds of threads are in use: The *V thread*, the *U. S. Standard thread*, and the *Whitworth* or *English Standard*. In the V threads the angle of the sides is 60° at the top and bottom. In

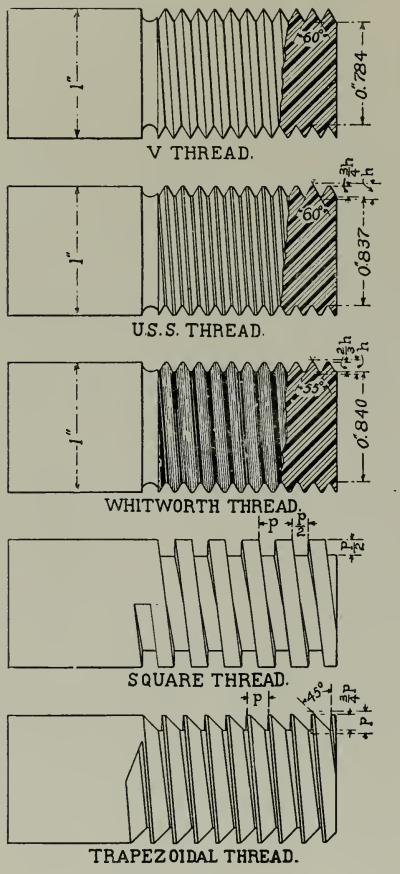


FIG. 210.

the U. S. Standard the sides of the thread are inclined at an angle of 60° and the angles at top and bottom are truncated to form a flat, one-eighth of the pitch in width. In the Whitworth thread the angle of the sides is 55°, and one-sixth of a V thread is rounded off at the top and bottom.

The U. S. Standard prescribes the number of threads per inch for each size of screw as well as the shape and dimensions of the thread, as tabulated in the Appendix. Screw threads are not only used for fastenings, that is, as a device for holding two or more pieces together, but they are also used for communicating motion, the two forms of thread in common use being shown in Fig. 210, are known as square thread and trapezoidal thread.

The pitch of a screw is the distance it advances along its axis in one revolution, thus the pitch of a screw with twelve threads to the inch is one-twelfth of an inch; both these expressions are used in referring to the pitch.

Screws may also be right-hand or left-hand, Fig. 211; a right-hand screw enters its nut by turning it clockwise; the thread of the left-hand screw, being at a reverse inclination to the axis, enters its nut on turning it counter-clockwise.

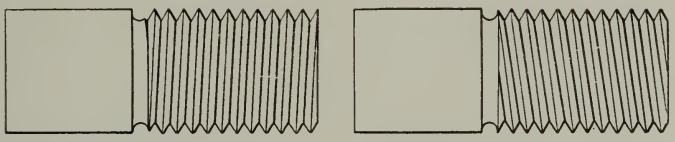


Fig. 211.

For small diameters and in using a steep pitch, double, treble, and quadruple threads are used, which consists simply in cutting two or more parallel threads in the pitch instead of one.

Screw threads are cut from the solid stock, either by means of a pointed cutting tool, or chased in a lathe fitted with an accurate leading screw, or by means of taps and dies. Where accuracy is desired the threads should always be cut in a lathe. Generally all screws used for fastenings are cut with taps and dies, while those used for communicating motion are cut in the lathe.

Bolts-Studs.—The common forms of bolts in general use, Fig. 212, are the square head and nut, the hexagon head and nut, the snap or round-head bolt with square nut, and the carriage bolt and nut, this latter being fitted with a square under the head to prevent its turning in wood. Body-bound bolts or coupling bolts are turned and fit closely into reamed holes. A *stud bolt* is a bolt threaded at each end and used in places where one of the pieces to be secured

can be tapped. The projecting end of the stud is made long enough to receive the work together with the securing nut. The ordinary forms of the plain and collar studs are shown in *E* and *F*, Fig. 212. Studs are set in place by entering two nuts on the upper end so that they come together and then turning on the upper nut, or by means of a Stillson or pipe wrench on the unthreaded portion, using care not to burr the material, or, still better, by means of a *stud driver or box K*, Fig. 212, consisting of a cap with internal threads to fit the studs. A small piece of copper is inserted in the bottom of the socket to prevent injury to the stud, the box screwed on until

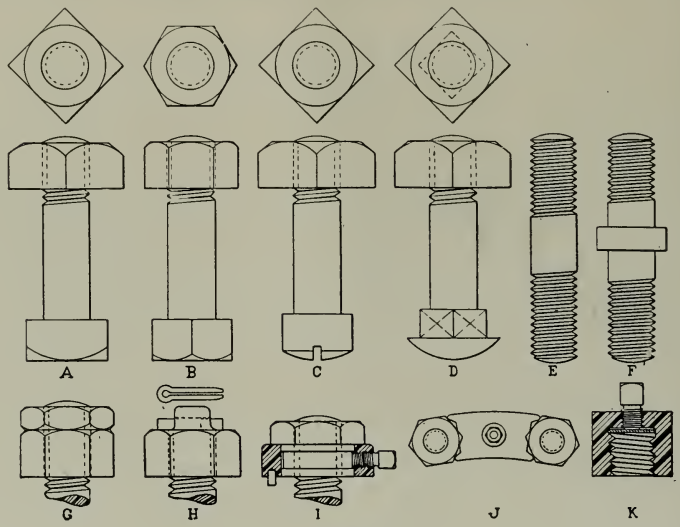


FIG. 212.

the end of the stud, bottoms, when by applying a wrench to the square box end the stud may be screwed in place up to the end of its threaded part. By a smart back turn the stud-driver may then be loosened and unscrewed.

Locking Arrangements.—To prevent nuts from gradually unscrewing, owing to vibration, double nuts are used, the check nut being thinner than the securing nut and usually placed on the outside from the fact that ordinary spanners are often too thick to hold the check nut if placed inside, but as the whole load may come on the outer nut a better arrangement would be to have the thick

nut at the end. Other means of locking are by means of set screws, or allowing the bolt to pass through the nut far enough to permit a hole to be drilled through it and a split pin inserted. Lock plates also are frequently used as, for instance, in the securing bolts of propeller blades and illustrated in *J*, Fig. 212.

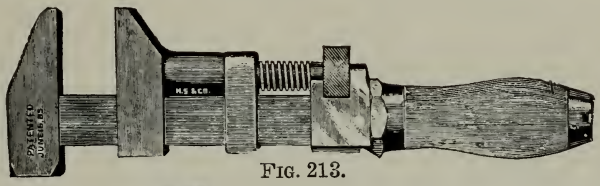


Fig. 213.

Fig. 214.

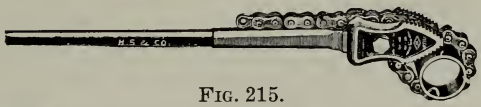


Fig. 215.

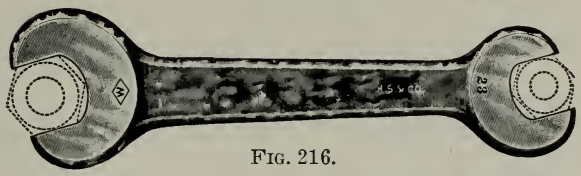


Fig. 216.

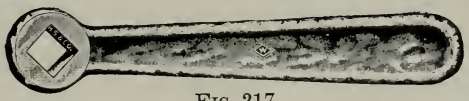


Fig. 217.

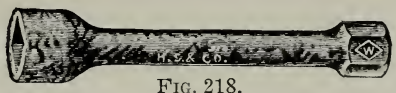


Fig. 218.

Wrenches.—Of the different wrenches in general use may be mentioned the screw wrench, Stillson wrench, pipe wrench, the solid wrench, both single and double ended, the box wrench which has a closed opening, and the socket wrench.

These different tools are shown in Figs. 213 to 218, and need no further description. Solid wrenches are preferred to the adjust-

able when standard finished nuts are to be turned, as they fit better and there is less chance of marring the surface and corners of the finished nut. The socket wrench is used to reach nuts in corners or in deep or inaccessible places, where the use of the other types of wrenches is impracticable. Pipe wrenches are used in connecting up piping, the forms of the ordinary wrenches not being possible for this work. The screw wrench is one of the most familiar of

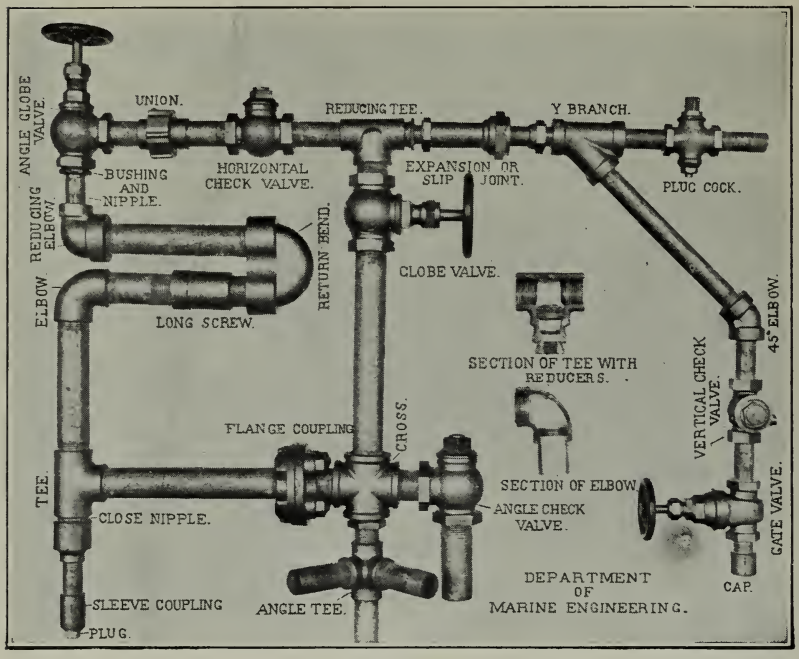


FIG. 218a.

machinist hand tools and probably the one most abused, as being so much in evidence it is used as a hammer and for other purposes for which it was never designed. In the use of this wrench, the force should be applied and the wrench turned in the direction of the arrow, for then the short leverage comes on the fixed weaker jaw and with less tendency for the wrench to bind in the shank between the jaws, which is the point at which these wrenches fail under an overload. The Stillson wrench is used for pipe fitting and round work.

Pipe Fittings.—In connecting up piping the following fittings, illustrated in Fig. 218a, are in common use. As midshipmen have been brought in frequent contact with them in the Drawing Room Course and in their practical work, they need no description and their use is evident from the illustration.

Angle globe valve.	Long screw.	Y branch.
Bushing.	Return bend.	Cross.
Nipple.	Union.	Angle tee.
Reducing elbow.	Horizontal check valve.	Angle check valve.
Elbow.	Reducing tee.	45° elbow.
Tee.	Expansion joint.	Vertical check valve.
Close nipple.	Plug cock.	Gate valve.
Sleeve coupling.	Globe valve.	Cap.
Plug.	Flange coupling.	

CHAPTER IX.

MACHINE TOOLS—THE SCREW CUTTING POWER LATHE.

As previously stated, machine tools in general, in the machine shop, may be classified as *lathes; planing, shaping, and slotting machines; boring and drilling machines; and milling machines.* In the varied classes of work performed there are many modification of tools embraced under these heads, and these in turn have varieties made especially for the particular form of work where duplication is a principal feature, or where one particular class of work is produced, but the general principles employed are about the same. Under the circumstances it would be impossible to describe within limits, even the principal modification of these tools, so that only the typical representatives of the four divisions mentioned above are discussed.

Of the above four classes, the *lathe* carries out the principle of rotating the work to a stationary cutting tool, excepting in so far as moving the tool to a comparatively small amount for the feeding operation. In *boring mills* the tools, or the bed and work, are made to revolve, depending on the size and configuration of the work. In *planing machines* the work has a horizontal reciprocating motion with one or more stationary cutting tools, while in the *shaping* and *slotting machines* the work is fixed and the tool in the former has a horizontal and in the latter a vertical reciprocating motion. In these latter tools the forward motion only has any cutting effect, the tool in the backward motion doing no work; attempts with reversible tool holders having been tried but with poor success, due to want of rigidity. This difficulty will probably be surmounted by a type of revolving tool as employed in the milling machine, the reciprocation only giving the feed.

The Screw Cutting Power Driven Lathe.—This lathe is extensively used for general shop work and is made in various sizes from 8 inches up to 90 inches or more swing and any length of bed desired. By the *swing* of a lathe is meant the maximum diameter of

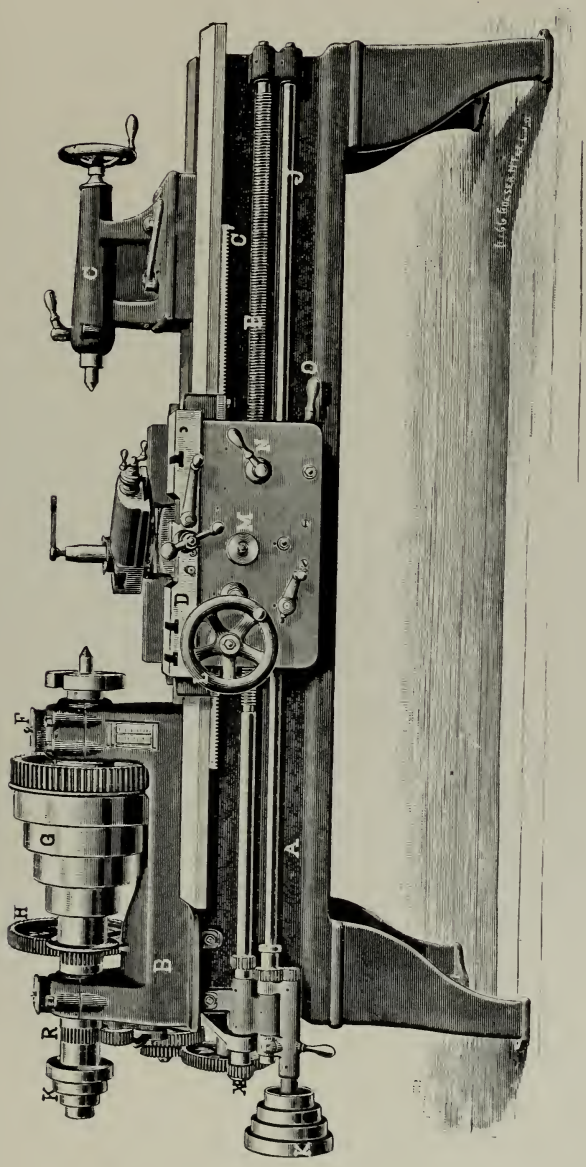


FIG. 219.

the work that can be carried, the radius of which is limited to the distance between the *lathe center* and the *bed*. The length of the work carried is limited by the available length of the bed between the *head*, and *tail or dead center*.

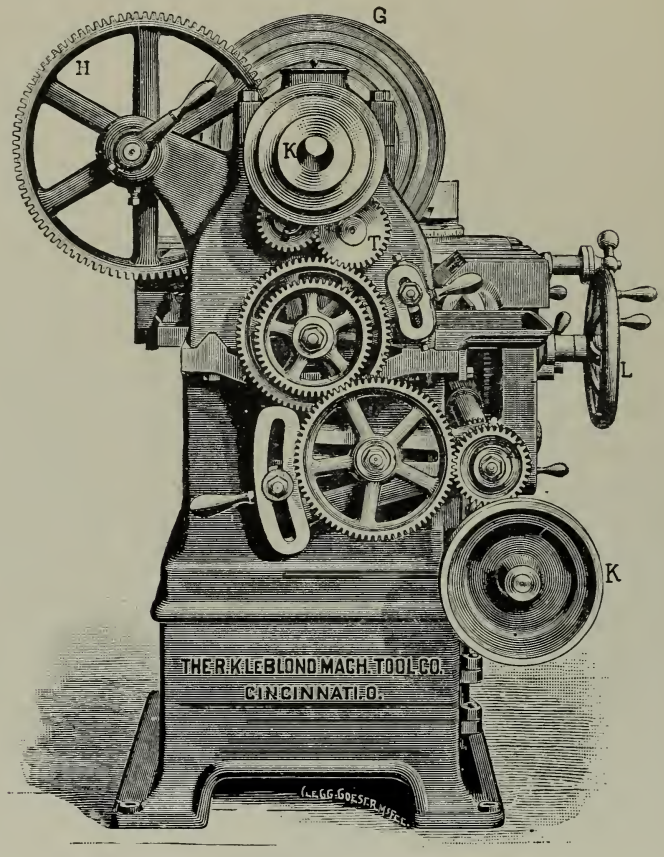


FIG. 220.

In Figs. 219 and 220 is represented a modern screw-cutting lathe of 24 inches swing and 12 foot bed, and is known to the trade as *double geared, self-acting, screw cutting power or engine lathe*. The term double geared refers to the *back gear*, by means of which the speed and power can be varied beyond the variation of spindle speeds given by the steps on the cone pulley alone. In a *single-*

geared tool, generally employed for hand or foot lathes, the *cone* is fixed to the *spindle,* the number of changes in the spindle speed depending upon the number of steps on the cone. In a back-geared lathe the cone may be disconnected from the spindle by a coupling, and the motion transmitted through the back-gearing. In large-size lathes, triple and quadruple gearing are employed, and this means simply additional gearing for still further reductions by the back-gearing. By the term *self-acting* is meant that all the different speeds of the cutting tool can be made automatic in their action.

The cutting speeds vary, for different metals, from 30 feet per minute for brass to about 15 feet per minute for steel, and this linear velocity at the surface of the work is constant. Since the

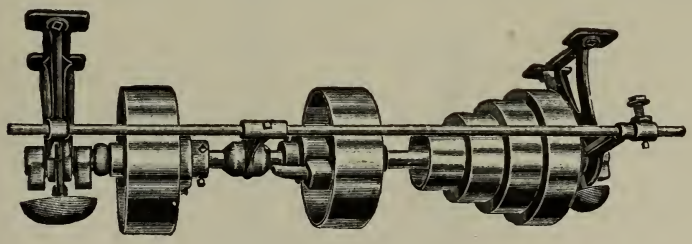


Fig. 221.

diameter of the work varies, the angular velocity must be capable of being varied, and to do this without altering the angular velocity of the main driving shaft, cone pulleys and back gear are used. The counter-shaft above the lathe receives its constant motion through a belt from the main shaft; and on this counter-shaft is fitted a cone pulley similar to that on the lathe spindle but with its steps reversed end for end. Since the sum of the diameters of the driving and driven pulleys is a constant, the belt will fit any pair of the cone steps and a change of angular velocity in the lathe can be effected with a constant speed of the driving shaft.

In Fig. 221 is a sketch of the counter-shaft usually applied to lathes and consists of the shaft, two hangers, cone pulley fixed to the shaft, and two friction pulleys riding loosely on the shaft. One of these pulleys is connected to the main or driving shaft by an open belt, thus having a motion in the same direction, while the

other is connected to it by a cross belt, consequently its direction of motion is the reverse of that of the main shaft. The counter-shaft is thrown into gear with either of the friction pulleys, by means of the clutches shown, engaging either end of the conical pointed collar, and consequently that pulley engaged gives the direction of motion to the counter-shaft, cone pulley, and thence to the lathe, by the cone-pulley belt. The friction pulleys are shifted from side to side by a horizontal rod operated by a long wooden handle, reaching down just over the lathe.

The back gear acts as follows: In Fig. 222 the conical pulley and pinion is shown at *A* and *B* fixed together, but loose on the

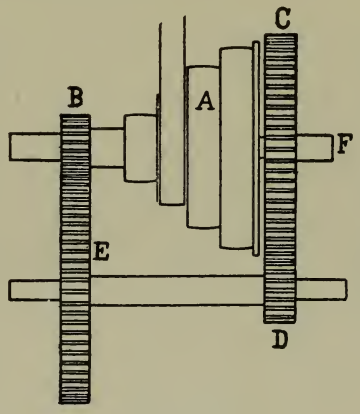


FIG. 222.

lathe spindle and revolving on it. In front of the large wheel on *A* is the spur wheel *C*, secured to the spindle, and gearing into this is a pinion *D*, keyed to a short shaft parallel to the spindle. Upon the other end of this shaft there is a spur wheel *E* geared into the pinion *B*. Motion is transmitted to the cone by the belt shown in the figure, then to the parallel shaft through *B* and *E* with a reduction of speed, then to the spindle *F*, through *D* and *C*, with a further reduction. To enable a quick speed to be given and the machine run as a single-geared lathe, a bolt is inserted through the spur wheel *C* into the face of the cone pulley, (thereby connecting up the pulley and mandrel), and disconnecting the back gear *ED*, which can be readily and neatly done by means of its eccentric bear-

ings. The variation and speed obtained by means of the step cone and back gear is very considerable. Assuming a four-step cone with cone diameters from 4 to 12 inches and counter-shaft cone of the same range, if the belt is run on the small cone step of the spindle and the counter-shaft is making 125 revolutions per minute, the spindle will make 375 revolutions per minute. By shifting the belt to the largest spindle step, the velocity of the spindle is reduced in the ratio of 3 to 1, or to $41\frac{2}{3}$ revolutions per minute. If the back gearing is thrown in gear and the pinions have each 24 teeth and the spur wheels each 84 teeth, the further reduction would be $\frac{24}{84} \times \frac{24}{84} = \frac{1}{12.25}$ and the spindle now revolves at the rate of 3.4 revolutions per minute; thus by the use of the cone pulley and back gear we can obtain eight variations of spindle speed as follows:

Revolutions per Minute.

Without Back Gear.	*With Back Gear.*
$375 — 175 — 89\frac{2}{7} — 41\frac{2}{3}$.	$30.6 — 14.2 — 7.2 — 3.4$.

The fundamental parts of all lathes are, referring to Fig. 219: The *bed A, head stock B, tail stock C, tool carriage D,* and *leading*

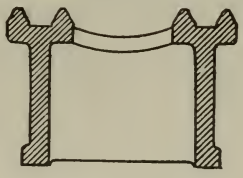


Fig. 223.

screw E. The bed is made heavy and rigid in order to reduce the deflection to a minimum; of the shape shown in cross-section in Fig. 223, and consisting of two parallel beams or cheeks tied along their lengths by cross girders and topped with the *shears,* accurately planed on the top of the bed. The head and tail stock rest on the inside pair of shears, while the carriage is supported on and moves along the outside pair. For the smaller size lathes the bed is supported on legs at the ends, and as the bed increases in length, intermediate supports are fitted or a *box framing* used along the whole length.

Head Stock.—The head stock is firmly secured at one end of the lathe to the inner shears, and in connection with it is the following mechanism: *Live spindle* and *spindle bearings F,* the *step cone G, back gearing H, feeding screw J,* and *leading screw E.* The spindle and bearing are accurately fitted so that the center rotates exactly parallel with the shears, as the accuracy of the work performed on the lathe depends largely upon the character of the work in fitting up the spindle. Similarly, the leading screw is another important part, its thread cut with the utmost care supported in bearings at its ends, and truly parallel to the axis of the spindle. Spindle bearings can be adjusted for wear and the journals are made large

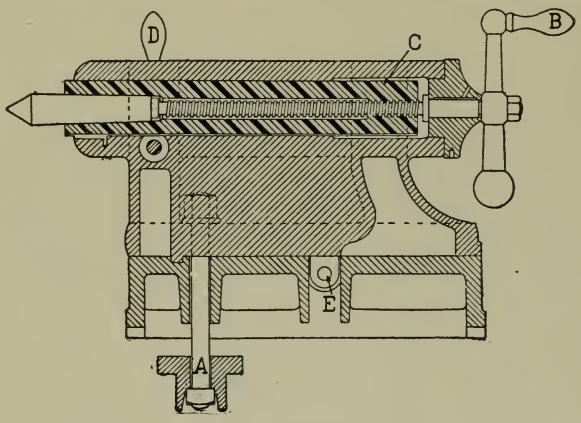


FIG. 224.

to reduce this wear to a minimum, while an adjustable screw thrust, at the end bearing, takes the axial thrust.

Tail Stock.—The tail stock, Fig. 224, is neatly fitted to the inner shears, along which it moves and can be securely clamped to them at any desired position, by a bolt and clamp *A.* The tail stock carries the *tail spindle,* and its axis should coincide exactly with that of the head spindle. After it is clamped a still finer adjustment can be given by means of the hand wheel *B,* thus moving out the inner sleeve *C,* containing the spindle, which can then be locked in position by means of the bolt *D.* Tail spindles are usually provided for lateral adjustment by set screw *E,* for the purpose of turning external tapering work between the centers, and also for

adjustment in bringing the centers exactly in line for turning parallel pieces.

Carriage.—The carriage moves along the outer shears, carries the *slide rest* and cutting tool, and is gibbed to the faces directly under the outer shears. The *apron* is on the front side of the carriage, tongued and grooved into it, and contains all the feed mechanism. The carriage is actuated by the spindle in two ways, either through the leading screw and change wheels at the left-hand end, or by means of the feed rod or shaft and its connections. The leading screw drive, except in very small lathes, is only used for the drive in screw cutting, and is consequently protected from wear in indiscriminate work. The arrangement of the change wheels is shown in Fig. 228, consisting of a spur wheel X attached to the end of the leading screw, and a pinion R to the left-hand end of the spindle, which is prolonged beyond the bearings for this purpose. Connection is established between the pinion and spur wheel by an intermediate wheel or wheels, with attached pinions. But since the leading screw is to be driven at variable speeds, the size of the change wheels and intermediate wheels vary and must have an adjustable support obtained by mounting them on a radial arm instead of a fixed bearing, the arm being movable about the axis of the leading screw. The leading screw having been given the desired rotation by this gear, the carriage may be put in connection with it or disconnected by means of two half nuts, shown in Fig. 227, moved together or separated by means of the handle.

The carriage can also be moved along the shears by means of the feed rod J and its connections. The method of transmitting the motion varies with the different makes of lathes, and the feed rod may be back of the bed or directly in front, under the feeding screw. Generally the feed rod is driven by belt and provided with three changes of speed by stepped cones, as shown at K-K in Fig. 219. If finer or coarser feeds are desired, lathes are supplied with a change-gear connection with the feed rod, or by connections with the change-gear mechanism of the leading screw. The feed rod is splined, fitted with a keyed sleeve sliding over the rod and carrying a bevel gear, which acts through a clutch and gear wheel to a pinion, which engages the rack C' under the front edge of the bed, behind the apron, and feeds the carriage along the shears. For feeding

across the face of the work, motion is communicated in a similar manner to the pinion of the cross-feed screw. By securing either clutch the feed will be given either along or across the shears.

Slide Rest.—The cutting tool is carried by the *slide rest* which, in its simplest form, is a single-tool post or clamp in which the tool

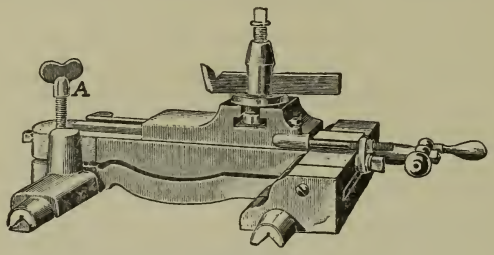


FIG. 225.

is secured by a set screw, the rest being gibbed to a single cross shear, thus giving motion to the rest at right angles to the axis of the spindle. The rise and fall rest, Fig. 225, is a modification of the simple slide rest, in which the tool post is raised or lowered by means of the elevating screw *A*.

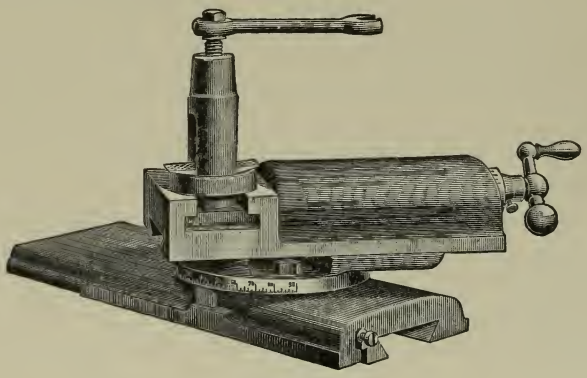


FIG. 226.

The compound rest, Fig. 226, has a regular automatic cross-feed, together with an auxiliary feed for operating at any angle with the spindle axis, and which can be made automatic in its action. In all lathes, methods are provided either by clamps or bolts for securing the carriage to the shears when the machine is used for cross-feed work.

Reversal of Feed Motion.—The carriage containing the slide rest must be capable of feed motion either forward or backward for right and left-hand threads as required. To effect such reversal idle gears S and T are usually interposed in the head-stock gearing, as shown in Fig. 228. Gear R is in connection with the lathe spindle, S and T rotate on studs secured to a radial arm or quadrant plate rotating on the stud B', while X is connected to the lead screw. When R is in gear with T the motion of X is right-handed, but if the wheel S is thrown into gear with R a left-handed rotation is given to X. The wheel S or T is thrown into gear with R by moving the handle attached to the quadrant its full throw up or down and then securing it in place.

Leading Screw.—Great care is exercised in the manufacture of the leading screw, as much depends upon the accuracy of this part. The carriage is driven by the leading screw when the lathe is used for screw cutting, by means of the leading screw nut. This nut is of brass, made in halves, and mounted under the apron. Connections can be made or broken at once by a lever on the outside of the apron, which closes or opens up the divided feed-screw nut. In order to cut threads of any desired pitch with the same leading screw, the requisite proportion between its speed and that of the spindle can be obtained by properly combining the *change wheels,* at the left-hand end, a set of which, consisting of about twenty wheels, is provided with every lathe.

The common arrangement for a set of change wheels is shown in Fig. 228. A spur wheel is attached to the end of the leading screw and a pinion to the end of the spindle, this latter carrying the rod to be operated upon. Connection is established between the pinion and spur wheel by an intermediate wheel alone or a train of wheels. The variable size of the pinion, spur, and intermediate wheels required in order to drive the lead screw at different speeds, renders an adjustable support necessary for one of the wheels, instead of mounting them on a fixed bearing, consequently the wheel meshing with that on the lead screw is mounted on an arm movable about the axis of the leading screw, and by means of a set screw in a circular slot, the arm can be clamped at such an angle as to enable this wheel to gear into the intermediate chain. At the same time this wheel, since it moves about the axis of the

lead screw, is brought into gear with the spur wheel of the leading screw.

Mechanism under the Lathe Apron.—The front view of a lathe in Fig. 219 shows the leading screw traversing the length of the lathe in front of the bed, and underneath it the feed rod. On the apron are shown several levers and wheels. The large hand wheel on the left *L* is for the purpose of running the carriage forward and backward, by hand, through the rack under the ways. The first lever to the right and below is for the purpose of separating the rack and pinion so that in screw cutting the carriage is operated by the lead screw alone. The knurled knob *M* in the center operates the rack wheel through friction discs, and gives an auto-

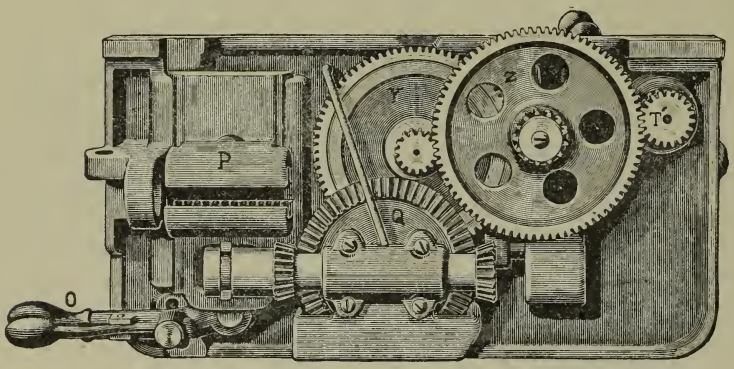


FIG. 227.

matic feed to the carriage through the feed rod and connections. The lever *N* to the right opens and closes the divided nut on the lead screw, thus putting it in or out of gear, and the lever *O* in the bottom right-hand corner gives a forward or backward motion to the carriage through the feed rod.

Fig. 227 shows the apron removed and the contained mechanism. The divided nut of the lead screw is at *P*, and when closed on the thread carries the carriage and cutting tool by means of the leading screw, at the rate at which the change wheels are set. The method of obtaining a forward or backward motion of the carriage by the feed rod is seen to be due to two bevel pinions on the feed rod, one or the other being thrown into gear with the circular rack *Q* by the

handle O. Motion is transmitted through a pinion back of Q to the spur wheel Y, and its pinion to the wheel Z, which engages the rack under the bed, and thus moves the carriage in one direction or the other. The small pinion T' is moved by the hand wheel L, and gearing directly with Z, enables the carriage to be moved directly by hand.

The exact pitch of the leading screw being known, a simple calculation shows the wheels to be used in cutting a screw of any number of threads to the inch. Each lathe is provided on the head stock with a table, which shows, for ordinary pitches, the size of wheels to be used, but the method is so easily calculated that any one using a screw-cutting lathe should be familiar with the method, which can be explained as follows:

Since the lathe is necessarily a copying machine, and in the case of screw cutting, the leading screw being the model, this screw can be reproduced at will on a bar between the spindles, by connecting up the spindle and leading screw by equal gear wheels, for, in each revolution, the leading screw would advance the carriage and screw-cutting tool through a distance equal to the pitch. Since the rod between the spindles is travelling at the same rate, the cutting tool will describe a thread upon the rod exactly similar to that on the leading screw. If a greater or less pitch is required on the rod, the spindle must revolve more or less rapidly than the leading screw, and this is accomplished in practice by the train of wheels before mentioned, called *change wheels,* which are made to conveniently connect the spindle and leading screw, so that they may be made to revolve with any desired relative velocity.

Let R, U, V, and X represent the number of teeth upon the wheels so marked, and assume that the spindle makes m revolutions, while the leading screw makes n revolutions in the same time, then x, the velocity ratio between the two, or the value of the interposed train of wheels, is

$$x = \frac{n}{m} = \frac{\text{pitch of screw upon spindle}}{\text{pitch of screw upon lead screw}}$$

But

$$x = \frac{R \times V}{U \times X} \cdot \frac{\text{pitch of screw upon spindle}}{\text{pitch of screw upon lead screw}} = \frac{R \times V}{U \times X}.$$

Hence the following rule:

From a fraction whose denominator is the number of threads per inch in the screw to be cut and whose numerator is the number of threads per inch on the leading screw. Multiply both terms by any suitable number to get teeth for the change wheels, and the numerator so obtained represents the product of the drivers, while the denominators, the products of the followers, or driven wheels, the wheel on the spindle end being a driver, and that on the leading screw, a follower.

Example.—Pitch of the leading screw $\frac{1}{4}$ inch. Required the gearing to cut a threaded bolt with a pitch of $\frac{1}{28}$ inch.

$$\text{Here } \frac{4}{28} = \frac{4}{28} \times \frac{500}{500} = \frac{50 \times 20}{70 \times 100} = \frac{\text{Drivers}}{\text{Followers}}.$$

To cut $13\frac{1}{2}$ threads per inch with a leading screw of $\frac{1}{4}$ inch pitch

$$\frac{\frac{4}{27}}{2} = \frac{8}{27} = \frac{8}{27} \times \frac{900}{900} = \frac{40 \times 20}{30 \times 90} = \frac{D \times F}{E \times G}.$$

As the leading screw is right-handed the above operation will cut a right-hand screw. Fig. 228 is connected up for a left-hand screw. In cutting a left-hand thread, the direction of motion of the leading screw must be reversed, causing the carriage and tool to move in the opposite direction. This is accomplished, as already explained in Fig. 228, under the heading of Reversal of Feed Motion.

It will be noticed in calculating the speed that no cognizance is taken of the size of the wheels *S*, *T*, and *W*. These are merely idle wheels, and while controlling the *direction* of rotation, do not have any effect upon the *speed* of rotation; for instance, taking all the wheels of the series, we have: $x = \frac{R}{S} \times \frac{S}{T} \times \frac{T}{U} \times \frac{V}{W} \times \frac{W}{X} = \frac{R \times V}{U \times X}$.

Screw threads to be accurate must be cut in the lathe, for in cutting threads by means of a screw die, parts of a nut are used for cutting, which fit the screw when it is completely finished and the first cut made upon the outside surface of the rod is that made by the apex of each thread and traces a line which properly is the inside helix in the bottom between the two threads. An error is introduced here at once in cutting threads by means of dies, for with screw threads of the same pitch, the inclination of the thread to the axis is less as the cylinder on which the thread is placed

becomes greater. This difference cannot be readily detected in small screws, but it exists, and is quite apparent in the fitting of large screws.

In screw cutting it is necessary to see that the cutting tool is securely fastened to the tool post and must be set at right angles to and level with the axis of the work. In setting the tool, the

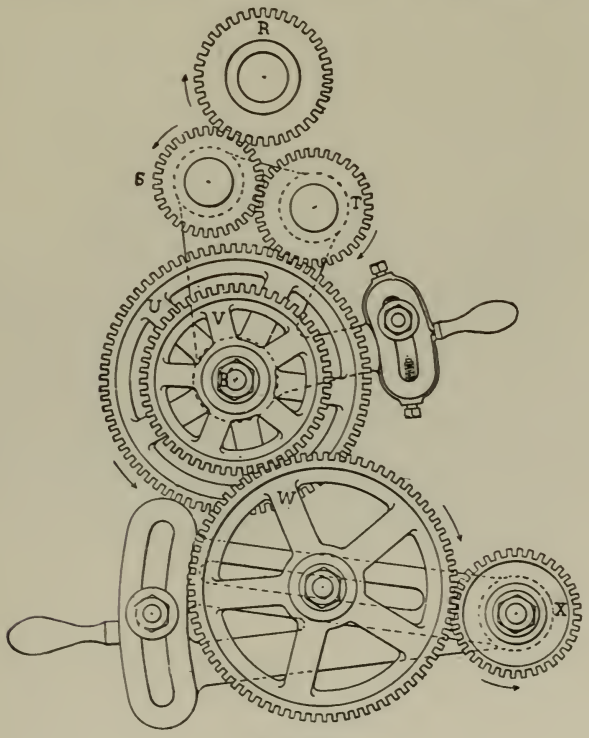


FIG. 228.

center gage is employed, as shown in Fig. 178, and level with the center. With a right-hand screw the rotation is such that the feed is towards the headstock, with a left-hand screw the direction of the feed is the reverse.

The amount to which the tool is further entered, after each cut, is generally regulated by a dial on the cross feed, and on finishing a cut the tool should be withdrawn clear from the work, before re-

versing the lathe, to bring the tool back to its starting point. In threading steel or wrought iron, oil should be constantly used on the edge of the cutting tool.

In cutting double threads, one thread is first completed, and in order to start the second, the point of the tool must be advanced axially a distance equal to one-half the pitch from its first position. To do this accurately, mark a tooth on the spindle and intermediate gear, drop the intermediate plate out of gear, and then turn the spindle gear through one-half a revolution. The gears are then

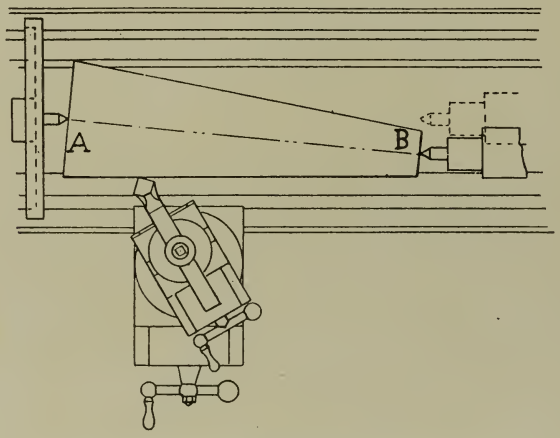


Fig. 229.

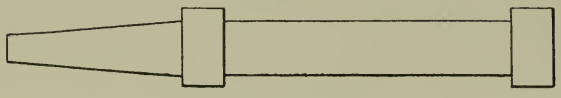


Fig. 230.

connected up again and the cut for the second thread taken. Other methods are, by having the face plate notched in different positions required, and by removing the work, place the tail of the driver in the notch that will give the desired lead, in this case the notch diametrically opposite that used for the first screw. For triple and quadruple screws similar methods are emloyed.

Taper-Turning.—Taper-work may be turned in several ways between centers. The most general method with lathes not specially fitted with taper-turning attachments is by means of a side adjust-

ment on the tail stock, so that the upper part of the tail stock, with the tail center, may be moved across the bed to a limited extent by means of side adjusting screws. Under these circumstances the center line of the work will be at an angle with the line of action of the carriage and tool rest and tapered work must result. The amount of *set over* to be given from a parallel shaft can be determined from the fact that the set over should be just one-half the actual taper required. In Fig. 229, if the set over is $\frac{1}{4}$ of an inch at *B*, then the actual taper or difference in diameter at the ends *A* and *B* would be $\frac{1}{2}$ inch. If this rod was 4 feet long the taper would be

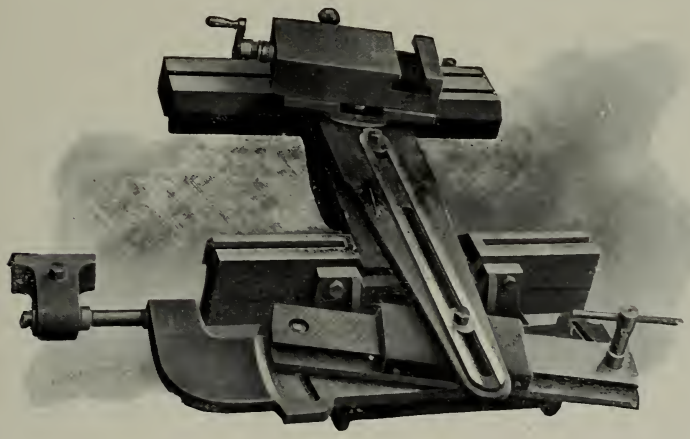


Fig. 231.

$\frac{1}{8}$ inch to the foot. Similarly, to obtain the set over for a rod 3 feet long to be tapered at the rate of $\frac{3}{8}$ of an inch to the foot, the difference in diameter at the ends would be $1\frac{1}{8}$ inches, and the set over would be half this, or $\frac{9}{16}$ of an inch.

Although there is always a mark on the body of the tail stock to bring the tail center back to its central position, it is frequently necessary to test its accuracy, when the marks coincide. For this purpose a long bar, fitted with collars, Fig. 230, is placed between the centers, and a light cut taken over each collar without changing the setting of the tool. Now caliper the collars: if the centers are in alignment, the collars will caliper to the same diameter: if not, repeat the operation until the measurements coincide.

The above method of setting for a taper is approximate, and from the centers not being in line causes undue wear and throws the work out of line. In quite a number of lathes in the Engineering Building can be seen a number of the *taper attachments,* of the different standard makers. One type is shown in Fig. 231, and the general principles in all are much the same. This attachment is located at the back of the lathe and actuates the tool rest directly from a sliding shoe moving on a guide, set at any desired angle with the shears of the lathe. The action of the taper attachment is independent of the cross-feed screw, but under the control of the operator for running in and out. By the use of the taper attachment the off setting of the tail center is avoided, and obviates the time and trouble in adjusting the tail center for parallel turning, after each operation of taper-work.

Its method of action is as follows: The guide is shown set and secured at any angle within the limit. A sliding shoe moves on this guide as the carriage moves along the shears, and being in connection with the tool rest by means of a screw, it pulls the rest towards or away from the work as the carriage advances, thus producing a taper cut to the degree desired, a graduated scale being marked on the end of the guide to determine the amount of the taper. When not in use the guide is brought to its central position and secured, the tool rest then following the natural feed given along the axis of the lathe, or at right angles to the bed across the face plate, by the action of the cross-feed screw.

In changing the gear wheels, where a variety of threads of different pitch are to be cut, the time employed amounts to quite an item in the cost of production. To avoid this loss of time several manufactures have put upon the market lathes in which these different changes of gear are all produced by simple lever movements. As a number of these machines are installed in the Engineering Building, as for instance the Hendey-Norton and the Lodge & Shipley lathes, a brief description is given below of the change gear mechanism, for use in the practical drills in lathe work.

A front view of the Lodge & Shipley lathe is given in Fig. 232, in which the general arrangements, with the exception of the feed

FIG. 232.

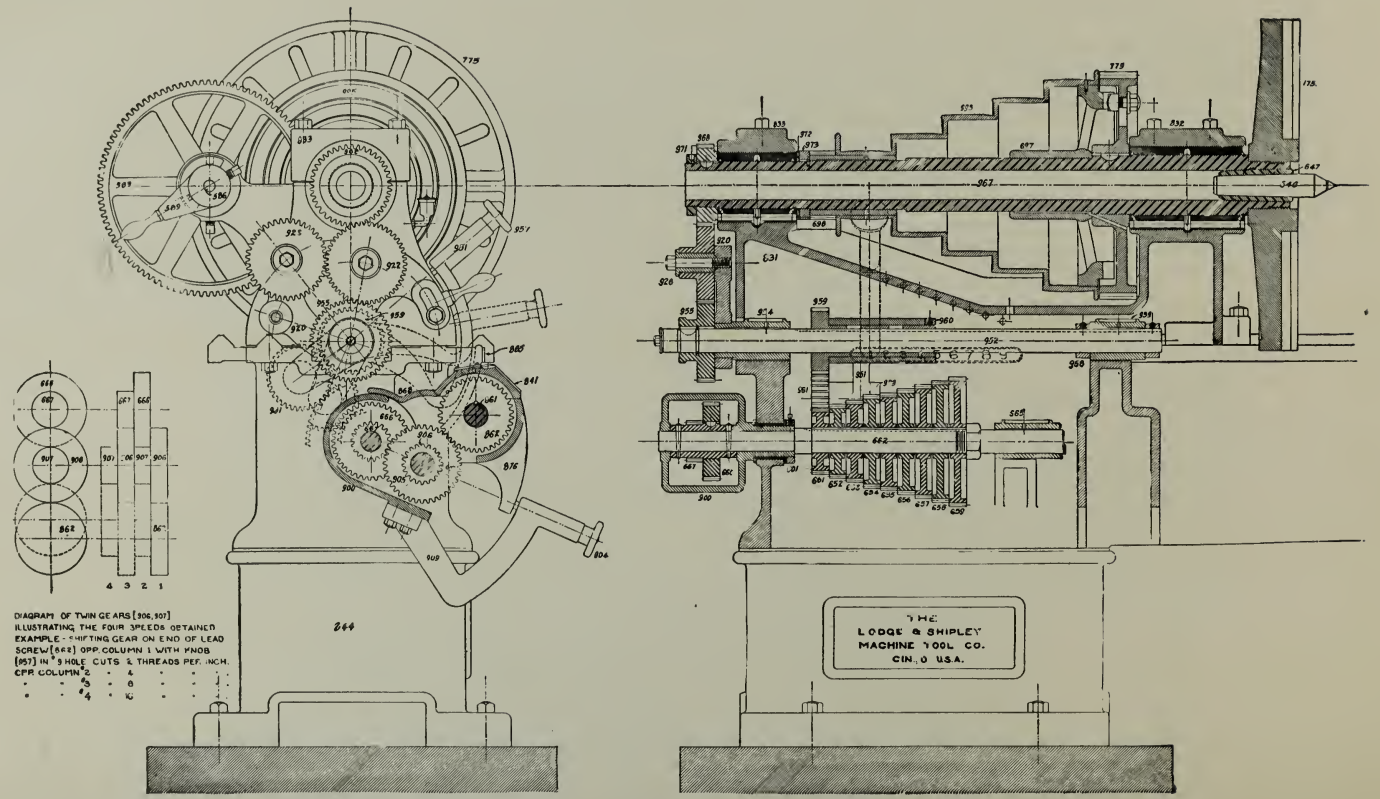


DIAGRAM OF TWIN GEARS [906, 907]
ILLUSTRATING THE FOUR SPEEDS OBTAINED
EXAMPLE - SHIFTING GEAR ON END OF LEAD
SCREW [662] OPP. COLUMN 1 WITH KNOB
[957] IN 3 HOLE CUTS & THREADS PER INCH.
CPR COLUMN 4 3 2 1
THE
LODGE & SHIPLEY
MACHINE TOOL CO.
CIN., O. U.S.A.

FIG. 233.

mechanism, is similar to that already described. Fig. 233 gives a section through the head stock and an end view, showing the arrangement of the gear wheels, while Figs. 234 and 235 show the arrangement of wheels in the upper end of the head stock for reversal of feed and for cutting extra coarse or extra fine threads.

The change gears, instead of being wheels separately attached as desired, are all mounted on a short shaft directly under the head stock. A knobbed lever or handle, 957, in front of the head, carries at its inner extremity a gear wheel capable of running either to the right or left, and may be dropped into any one of the cone of gears instantly and locked in place. On the left-hand extremity

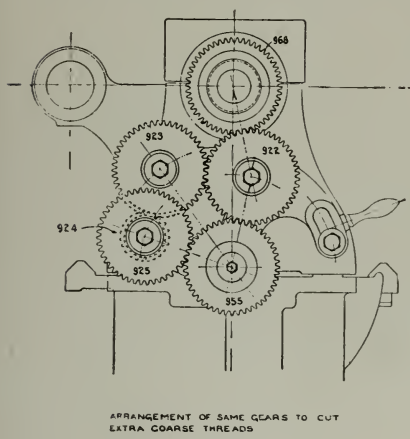


Fig. 234.

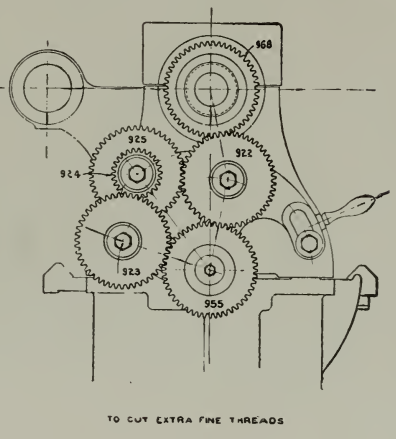


Fig. 235.

of this cone-gear shaft there are four gear wheels, into any one of which the gear wheel on the end of the lead screw may engage, thus by this latter mechanism there can be obtained four times as many changes as there are wheels in the cone of gears. This can all be obtained for the different threads shown on the index plate without removing a gear, with the consequent gain in time and labor.

Referring to the end view, the arrangement is similar to that previously described. The top wheel is on the end of the mandrel, the lower two are for reversal of motion secured on a quadrant with its lever. For right-hand threads, motion takes place between

wheels 968, 922, and 955. Wheel 955 drives an auxiliary shaft fitted with a splined gear wheel, so that it can be moved along the shaft longitudinally by means of the knob, 957, and engaging any one of the cone of gears by means of the idle wheel shown in the sketch, and can be locked by the knob in that position. Motion is thus transmitted to the cone-gear shaft. On the end of this shaft are two gear wheels, 666 and 667, each one meshing with one of a pair of twin gears on a shaft fixed in a movable quadrant plate working on the axis of the cone-gear shaft, and fitted with a knob

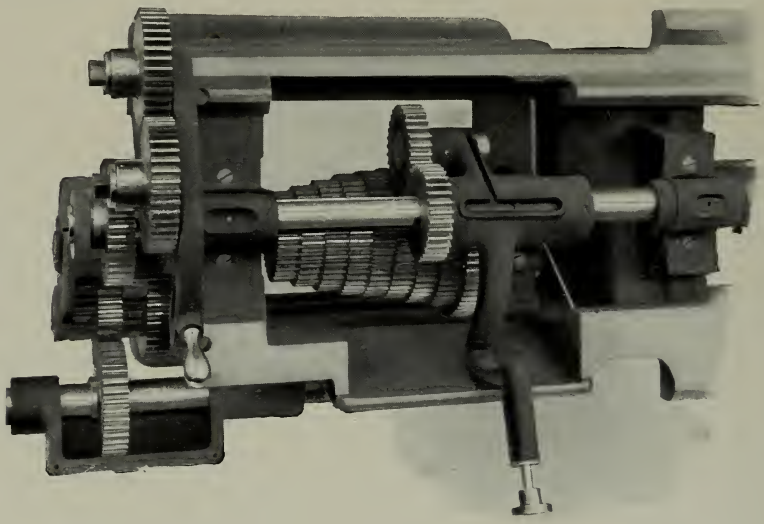


FIG. 236.

or handle, 904, by means of which the gear can be raised or lowered so as to mesh with the wheel on the end of the leading screw. This lead screw is splined so that the wheel can be moved along the lead-screw shaft so as to engage any one of the four wheels of the two pair of twin gear, thus giving additional variation to the feed of the leading screw.

In the arrangement the cone gear is equivalent to the change gear in the ordinary lathe arrangement, while the pairs of twin wheels are simply additional trains whereby the range is increased or decreased in the number of threads capable of being cut.

The index plate, Fig. 237, contains columns named threads and knob. If any thread, say 12 to the inch, is to be cut, the pointer is pulled to the column in which 12 is found, and the knobs placed in the hole indicated by the plate, viz., 7. The pointer moves the sliding gear wheel on the lead screw and the knob, 904, draws it into gear with any one of the pairs of twin gears. The resulting chain is as follows: The spindle and auxiliary shaft gear have each 36 teeth, hence one revolution of spindle gives one revolution of auxiliary shaft. The gear under knob 7 has 48 teeth, while the gear on the auxiliary meshing into it has 32 teeth, hence for one

Thds	Knob	Thds	Knob	Thds	Knob	Thds	Knob
18	2	9	2	4½	2	2	1
19	3	9½	3	4¾	3	2¼	2
20	4	10	4	5	4	2½	4
22	5	11	5	5½	5	2¾	5
23	6	11½	6	5¾	6	2⅞	6
24	7	12	7	6	7	3	7
26	8	13	8	6½	8	3¼	8
28	9	14	9	7	9	3½	9
30	10	15	10	7½	10	3¾	10
32	11	16	11	8	11	4	11
		FEEDS					
80 To 40		40 To 20		20 To 10		10 To 5	

Fig. 237.

revolution of spindle the cone-gear shaft makes $\frac{32}{48}$ revolutions, and $\frac{32}{48}$ revolutions of this shaft gives to the lead-screw shaft $\frac{32}{48} \times \frac{20}{40}$ revolutions, since the lead-screw shaft wheel is 40 teeth and the twin-gearing wheel meshing with it is 20 teeth. Hence, since the lead screw has 4 threads to the inch, we have the lathe set for cutting threads of $\frac{32}{48} \times \frac{20}{40} \times \frac{1}{4}'' = \frac{1}{12}''$ pitch.

Technical Terms.—The following are some of the technical terms used in connection with machine tools:

By *traversing* in lathe work is commonly meant those operations in which the tool moves along the length of the bed.

By the terms *surfacing* or *facing* is meant those operations in which the tool in feeding moves across the bed at right angles

to the line of centers, and in the operation producing a plane surface.

By the terms *burr* and *raw edge* is meant the sharp angle or edge of the cuts at right angles to each other. These edges are usually sharp and wire edged, and are capable of inflicting serious injury if touched while the work is in motion.

Truing up is the expression used in turning up an article to truth.

A surface is *true* when smooth and level; a cylinder is true when truly cylindrical, and similarly with other forms. A shaft between the lathe centers runs true when it revolves concentrically with cylinders formed on an axis joining the lathe centers. A surface on the face plate runs true when the surface revolves in a plane at right angles to the center of the lathe spindle.

Chattering is the noise made by the object being turned or operated upon, and is due to vibration. It is largely produced by the work being out of truth or the tool improperly set.

Centers are marks made by the center punch or drill at the ends of the work, and are intended to hold the work in the lathe or tool centers while being operated upon.

Back Lash.—If the direction of motion is reversed some little distance must be traversed before the work receives the action of the reversed motion, as in the case of change wheels. In this case the carriage does not instantly take the reverse motion, but must wait until the *lost motion* in the gear is taken up. Similarly, in the case of a screw-actuated piece of mechanism, the screw will move a part of a revolution on reversal before the part acted upon receives the effect, and is due to necessary *slackness* or *play* in the fit and gives rise to the movement called back lash.

Drunken threads or *drunken pitch* is the name given to a badly-made screw, such as one with an uneven pitch, or a non-uniform pitch, due to poor workmanship or inferior mechanism.

CHAPTER X.

LATHE TOOLS AND ATTACHMENTS.

Lathe Centers.—Cylindrical work is supported by lathe centers, made of high-grade crucible steel, turned to fit a standard taper hole, and having one end turned down to a conical point, the usual inclination in American practice being 60°. After finishing, the centers are hardened, and if not properly used, they quickly lose

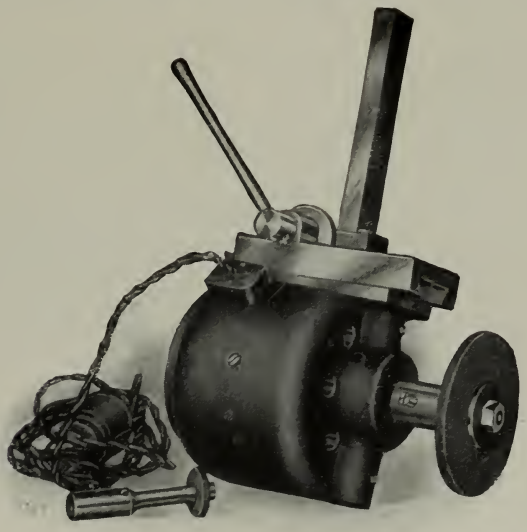


FIG. 238.

their points, with the consequent result of inaccurate work. The points when worn are now readily trued up by means of an emery-wheel attachment to a lathe, which possesses many advantages, among others it is unnecessary to soften the center points, and the center is ground accurately in place.

Center Truing Machine.—In Fig. 238 is shown a modern center grinding appliance, and in Fig. 239 the tool in position for grind-

ing. It is fitted up with an electric drive for the emery grinding wheel, as that method is the simplest and most convenient. The tool is provided with a shank, as shown, for mounting it in the tool post of the lathe, similar to an ordinary cutting tool, and the motor, with the grinder, placed at the desired angle to the center to be ground. The wheel is traversed by means of a quick-pitch screw and lever, and the cut adjusted by the lathe rest feed. The power for driving the wheel is taken from any convenient incandescent lamp socket, through the flexible cords attached to the motor. With the lathe in operation in a reverse direction to that of the grinder, the operation is quickly and accurately performed.

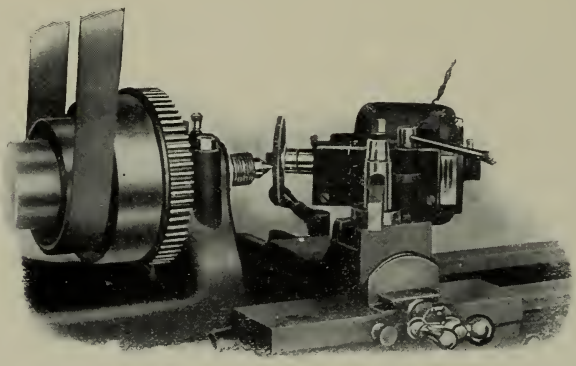


FIG. 239.

After having centered a piece of work and checked its accuracy by testing in the centers of a lathe, a small hole from $\frac{1}{32}$ to $\frac{1}{4}$ inch in diameter, depending upon the diameter of the work, is drilled in for a short distance, and then the hole counter-sunk with a counter-reamer or square center. This drilled hole performs a double duty, first, in protecting the delicate point of the lathe dead center, and at the same time acts as a reservoir for oil to lubricate the center.

As there is considerable wear on the bearing of the dead center, it must be well hardened and ground in position; the live center does not have the same work, and acting more as a support to the work, need not be so hard.

The face plate is illustrated in Fig. 240, and consists of a circular plate accurately bored and threaded to suit the thread of the spindle. Several radial notches for the arm of the dog, or driver to enter, are made in the face plate for work carried between the

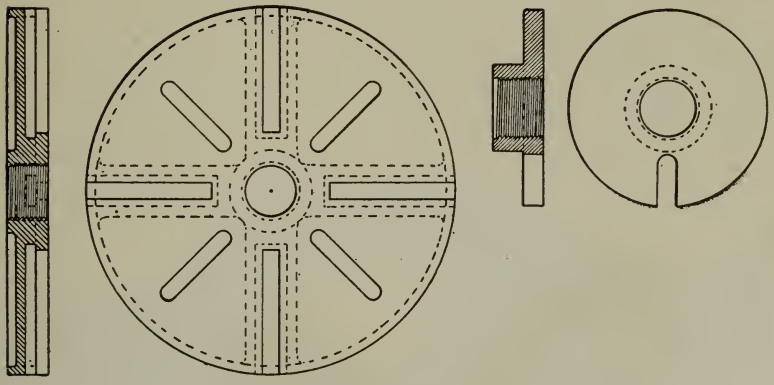


FIG. 240.

centers. Heavy work, or work not adapted to the centers, can be secured directly to the face plate by means of bolts or clamps passing through the radial slots.

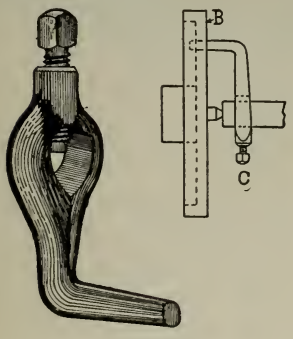


FIG. 241.

FIG. 242.

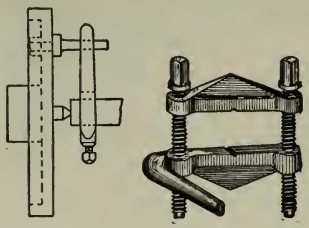


FIG. 243.

The face plate being screwed on the spindle, the *dog* connects the work with the revolving face plate, as shown in Fig. 241. The bent tail of the dog, at right angles to its body, engages with the slot *B*, and thus transmits the rotating motion of the spindle to the work. A set screw *C* secures the dog to the work and must be

set up hard enough to prevent slipping. As the points of these set screws are hardened, when set up they are apt to cut into the metal, so that when used on a finished end, a small piece of soft brass or copper should be interposed between the end of the set screw and work in order to prevent any injury to the surface. To overcome the objection to the liability of this shaped dog to spring, a *straight-tailed* dog or carrier, Fig. 242, is much employed and used with a stud or *driver* bolted to the face plate. Another dog much used is the *clamp dog,* Fig. 243.

For the class of lathe work not held between the lathe centers and necessitating some rigid connection between the spindle and the

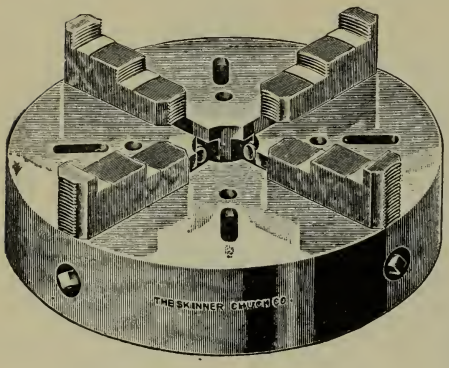


FIG. 244.

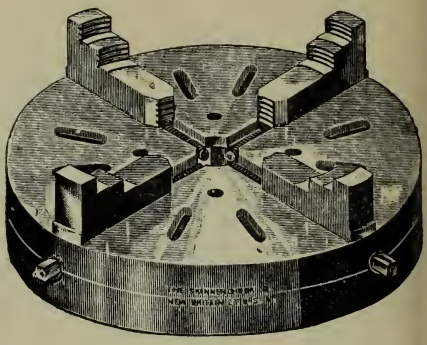


FIG. 245.

work, by clamping to the face plate, or the employment of the various forms of lathe chucks.

Lathe Chucks.—Instead of bolting the work to the face plate, chucks are used for adjusting the work more accurately and with greater ease. Chucks are divided into three classes—independent, universal and combination chucks. In the first, each jaw moves separately and is used for the heavier classes of work, or such as forms of an irregular outline. In the universal chuck the jaws move simultaneously to or away from the center, usually made with three jaws, but also made with two and four jaws, and is used for holding pieces circular in outside form. The combination chuck partakes of the nature of both the preceding and can be used either as an independent or an universal chuck.

Fig. 244 shows the independent jaw chuck, and consists of a substantial plate, containing two, three, or four ways into which the securing jaws are accurately fitted. Each jaw is operated independently of the others by means of a square-headed screw and a socket wrench, until the work is held in the central position desired. In order to conform to the shape of the work the jaws are made so that they can be reversed. Two jaw chucks are used for special work, such as that of irregular outline, as in the case of globe valves and brass cocks, which can not very well be secured in three or four jaw chucks.

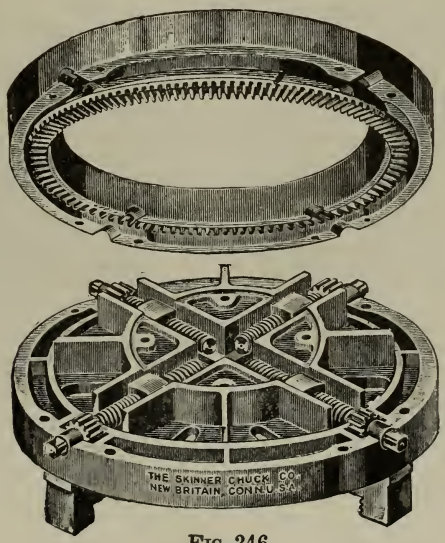


Fig. 246.

Universal Lathe Chuck.—Figs. 245 and 246 show views of the front and interior of one type of universal chuck from which it can be seen that the shell is made in two parts and secured by screws. Referring to Fig. 246, each jaw is secured to the sliding box by means of a stud and nut, the stud being a portion of the sliding box. Each jaw is moved by means of a screw and nut, as in the independent chuck. In the universal type, the ring back plate contains a rack gear in a recess, while at the extremity of the screw of each jaw, in the front plate, there is a pinion. When the ring back plate is secured to the front plate the pinion and rack gear are in

mesh, and the jaws may then be moved simultaneously either way, by means of a wrench applied to any one of the pinion nuts on the outside rim of the chuck.

Combination Lathe Chucks.—The jaws of this chuck are made to move universally by means of the rack gear and pinions, as in the preceding, and the jaws may be used independently by throwing the rack gear out of mesh with the pinions. This latter arrangement is briefly as follows: In Fig. 247 the chuck is universal and the pinion and gear in mesh. In Fig. 248 the stud nut on the back

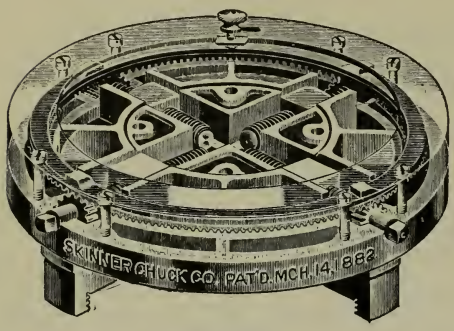


FIG. 247.

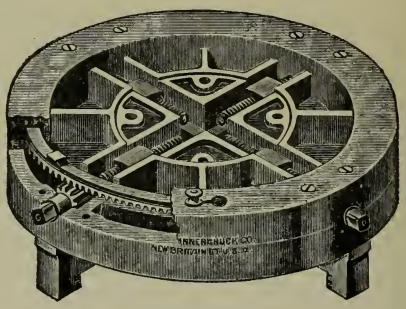


FIG. 248.

of the chuck has been loosened and the stud moved to the other end of the slot. This stud is connected with a cam ring, placed back of the rack gear, and the movement of the stud is conveyed to the cam ring, and the cams enter recesses provided in the back of the

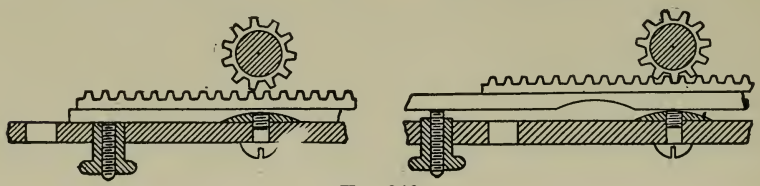


FIG. 249.

chuck, thereby permitting the separation of the rack and pinion gear, and the jaws are now independent. In Fig. 249 is shown the stud and cam mentioned, and the pinion in gear and out of gear.

Another type of chuck, of which numerous examples can be seen in the machine shop of the Engineering Department, is illustrated

in Fig. 250, and known as a scroll combination chuck. One particular advantage it possesses is that it is always ready, owing to its peculiar mechanism, to be used as an independent chuck, or as an universal, without shifting in or out of gear. The mechanism,

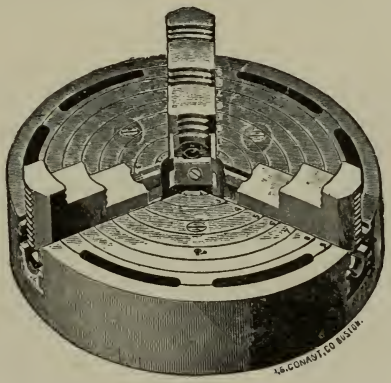


FIG. 250.

referring to Figs. 251 and 252, consists, first, of a slider and carrier *B* with the jaws, fitted with a screw *G*, working in a half nut in the slider, and by means of a socket wrench this jaw can be moved in and out in the usual manner independent of the others. Fitting

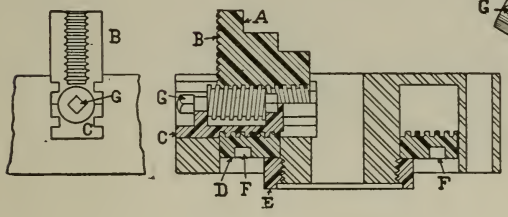


FIG. 251.

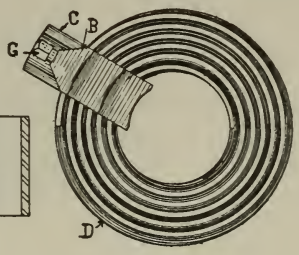


FIG. 252.

over this screw with a recess, is another part *C* of the slider with curved slots on its back. Engaging with these slots on the carriers is a scroll *D*, a plate with a spiral groove cut in its face, the back fitted with holes for a spanner wrench, by means of which the scroll can be turned, and the whole secured by a plate screwed in

the back. By turning the scroll with the spanner, the grooves engage the arcs in each slider, and then move all the sliders entire with the jaws simultaneously, and through the same distance, while by using a wrench on each screw *G* it is seen from the sketch only the part *B* of the slider and jaw moves, and with no movement

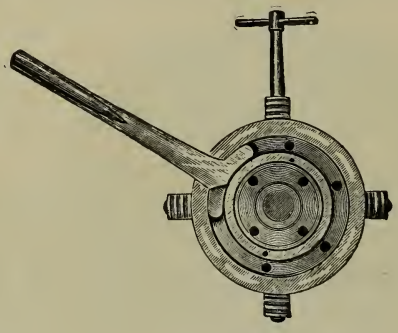


FIG. 253.

whatever of the back part of the slider or the scroll. Fig. 250 shows the chuck complete in perspective; Fig. 251, a section through the slider in which *A* is the jaw, *B* front half of slider, *G* is the screw working in the half nut on back of jaw, *C* the back half of slider, *D* is the scroll plate meshing with grooved arcs on

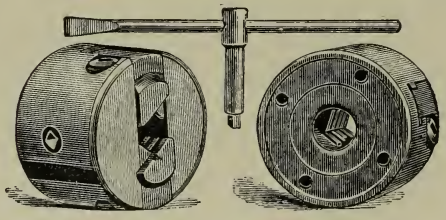


FIG. 254.

the back of each back slider, *E* is the securing plate, and *F-F* are the holes for the spanner wrench used in turning the scroll and moving all jaws together. Fig. 252 is a view of the inside of the scroll ring, showing the slider and the screw within the same for independent working. Similar letters refer to similar parts. Fig. 253 shows a back view of the chuck with spanner wrench and independent wrench in place.

Straight-shank drills are held in drill chucks, of which many varieties may be seen. One type in general use is shown in Fig. 254, and consists of a shank or body slotted through the end, the cavity thus formed being fitted with two sliders cut to form jaws for the drill. These sliders are brought in and out radially by means of a right and left-hand screw, engaging threads on the

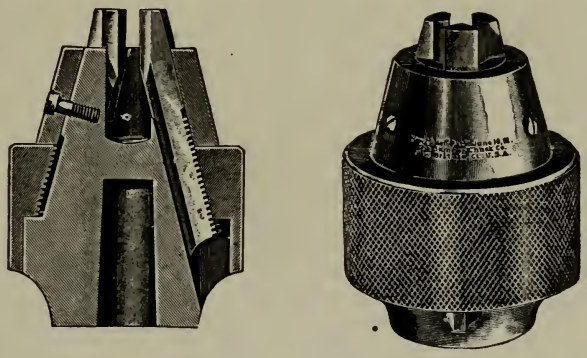


FIG. 255.

slider and body, and operated by means of a pin wrench and corresponding opening in the top of the screw.

In Fig. 255 is shown another type of drill chuck, the drill being held by the three jaws shown. By revolving the knurled nut, the jaws are moved outward and inward in the converging slots in the chuck body as may be desired.

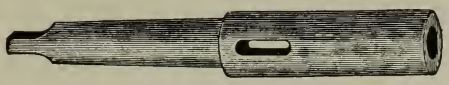


FIG. 256.

Where drills have taper shanks they are driven by *sockets,* Fig. 256, the shanks of the drill being always turned to standard tapers. A flat tang on the end of the shank fits into a corresponding recess at the end of the socket and thus drives the drill, aided by the friction between the shank and walls of the socket. The drill is forced out when required by inserting a taper drift or key in a slot cut in the socket and over the end of the tang.

The Center or Steady Rest.—Fig. 257 is another adjunct of a lathe, and consists of a framework with three sliding adjustable jaws, two being carried on the lower part of the frame and one at the top. The upper part is hinged so that work which must be removed can be replaced without disturbing the setting, by simply releasing the top clamp. The foot is clamped to the shears of the lathe at any point desired, and the tool is used to support work while it is being turned, and in screw cutting, or in boring long shafts, or work in which there is likely to be a deflection from its weight due to its unsupported length.

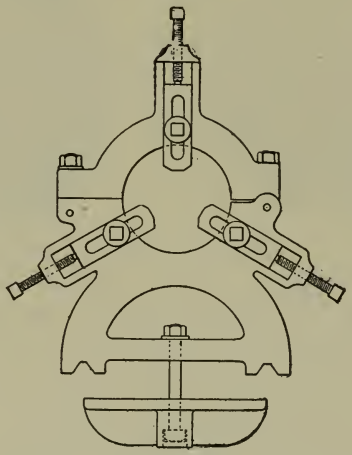


FIG. 257.

Mandrels.—A *mandrel* is a truly turned rod or shaft upon which work, that has been bored, is mounted in order to be turned or milled. An *arbor* is distinguished from a mandrel in the fact that the former carries and drives the cutting tools, as in the case of milling and sawing machines, while the latter carries the article to be operated upon by the cutting tool. As accurate work on the mandrel is required, it is apparent that it should fit the work to be supported without springing or bending, hence it should be as short as the work will allow and as stiff as possible.

The centers should be hardened to prevent wear and a consequent running out of true; they should be counter-sunk and with a small hole drilled in the bottom to prevent injury to the point of the

lathe center, and also for lubrication. The material employed is usually crucible steel hardened and ground, or annealed with the ends only hardened as circumstances demand. In the former case the uniformity in the size of the hole is better preserved in the different pieces of work. The mandrel is ground parallel for a suitable distance (depending upon the length of the work), to the standard size, and the remaining portion is slightly tapered in excess, about one-hundredth of an inch to the foot. This slight increase in diameter served to secure the work when the mandrel is forced into it, and judgment should be exercised in forcing the mandrel into the hole, as a great wedging action is produced which may result in splitting the work if brittle, or enlarging or tapering the hole, if the material is soft. In attaching the dog or carrier to the end of the mandrel the set screw is apt to injure the end, and whether or not the body is hardened it is always necessary to harden the ends. A flat is also milled or shaped on the ends for the dog screw to bear against. Standard mandrels are manufac-

Fig. 258.

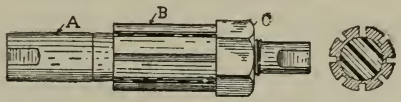


Fig. 259.

tured, and in the market, in regular sizes ranging from one-fourth of an inch in diameter and of appropriate length up to six inches diameter, the usual form being illustrated in Fig. 258.

Expanding Mandrels.—Another plan of support for work having a hole through its center is known as the *expanding mandrel.* While open to the objection of complication, with the consequent wear interfering with the continual accuracy of the tool, it possesses the advantages of a parallel grip in the bore of the work, and a less number of mandrels required to fit all holes in a given range. Fig. 259 shows one type of an expanding mandrel in which the mandrel *A* is made with a slight taper. A cast iron bushing *B* fits accurately the taper of the mandrel and is ground externally to the exact diameter required. The bushing is slotted longitudinally through its thickness, while on the rest of the surface a number of parallel additional slots are milled, but not passing entirely through the thickness of the bushing, and when placed in the hole it is slightly expanded by setting up on the adjusting nut *C.*

Lathe Tools.—Considering, first, the shape and proportions of these tools and referring to Fig. 260, *A* is the *relief angle* or *clearance, B* is the *top rake, C* is the *tool angle,* and *D* the *cutting angle. A* is sometimes called the *bottom rake,* while another angle made with the top of the tool and on either the right or left side, is called a *side rake.* The best values to be given, as determined by investigators, are as follows:

	Cast iron.	Wrought iron.	Brass.
Cutting Angle	54° to 70°	55° to 65°	66° to 80°
Clearance Angle	3°	4°	3°
Tool Angle	51° to 67°	51° to 61°	63° to 77°

The larger the angles of clearance and top rake are made, the more pointed or acute is the cutting edge, with a resulting finer and smoother cut, while upon the magnitude of the clearance angle depends the strength of the tool, for the cutting edge receives a

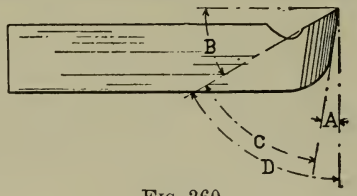


FIG. 260.

stronger support the smaller this angle is made. For brass, the cutting edge is made with no top rake, and with a clearance somewhat less than for wrought iron.

The ordinary lathe tool is made of tool steel, rectangular in cross-section, with one end forged to the required shape, which depends on the character of the material to be cut and the shape desired. The cutting end is then hardened, tempered and ground. The tools are redressed from time to time as the cutting edges wear away.

Turning tools in the slide rest are placed level, with the point of the tool at the height of the centers in work of large diameter, but little difference is experienced if the point of the tool is a little above or below the line of centers, but in work of small diameter, if the tool is not at the height of the center line, either rubbing takes place with a diminished capacity, or there is a tendency developed for the work to lift and spring out of the lathe.

A few lathe tools of the ordinary general type are represented in Fig. 261, but many variations of these are in use to meet the requirements of special cases.

1-2. Right and left-hand side tools.
3-4. Right and left diamond-point tools.
5. Round-nose tool.
6-7. Straight and bent cutting-off tools.
8. Straight threading tool.
9. Inside threading tool.
10. Inside boring tool.
11. Bull-nose tool.

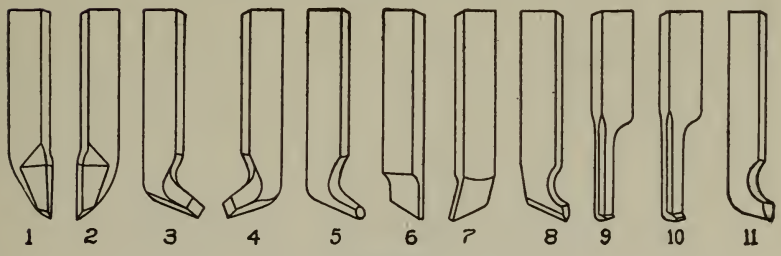


Fig. 261.

Tool Holders and High-Speed Steel.—An important item in machine-shop management and in engineering construction is the speed of cutting tools. The speed of the tool is limited by the frictional heating of the tool, and its consequent softening by drawing its temper, so that for wrought iron and mild steel the limits were from 10 to 30 feet per minute. Some increase was made on the introduction of a self-hardening steel in which higher speeds were attained, but the tools were rapidly broken in wear or abraded out of shape. Within the past five years there has been introduced various brands of high-speed steel, cutting three or four times faster than the best tools of the recent past, and possessing a remarkable durability. In some cases the chips are heated to a dull red in the operation of cutting, while the tools are nearly as hot. This steel will stand long, severe and continuous usage without re-grinding, and this, together with the increased strength, effects a great saving in time and labor, otherwise wasted in removing,

grinding and replacing the tool. Deeper and wider cuts can also be made, and this, together with the high speed, effect a considerably greater weight of metal removed per foot of travel, with a consequent cheapening in the cost of production.

FIG. 262.

Speeds of from 80 to 120 feet per minute upon medium hard steel have been attained in ordinary everyday work, while roughing cuts have been made at the rate of 90 feet per minute with one-quarter inch feed and one-quarter inch deep.

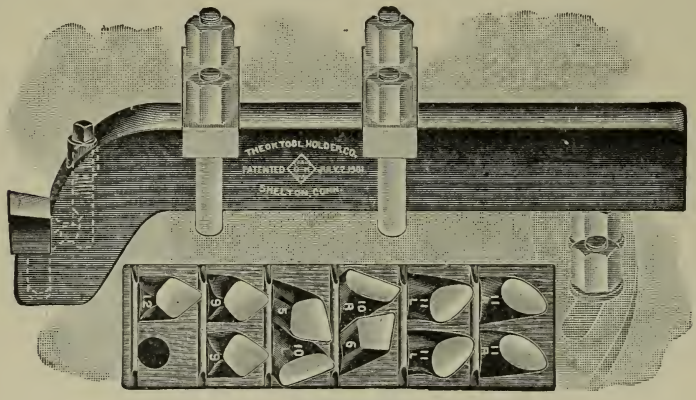


FIG. 263.

The price of the material is very high as compared with the ordinary tool steel, but is more than counterbalanced by its value as a time-saver. On this account the tools are not forged solid, as in the older way, but the cutting portions are forged and ground, then inserted in a tool holder and held by a set screw or other fastening, as illustrated in Figs. 262 and 263, which are types of the tool

holders in common use, and applied to several machine tools in the machine shop of the Engineering Building. As a number of cutting points can be used in one holder, one tool fashioned in this manner takes the place of several ordinary tools.

Of the actual composition of the various high-speed steels now in general use but little is known except by the manufacturers, but in general tungsten is an important ingredient, as is also chromium, while manganese, nickel, silicon and molybdenum are also factors to a certain extent.

For a more extended description of high-speed steel and the character of the work performed, see Appendix.

Owing to the difficulty in grinding screw-threading tools without changing their form, tool holders similar to the preceding are much used, and supplied with tool points, which can be correctly ground without difficulty.

CHAPTER XI.

OTHER FORMS OF LATHES AND MACHINE TOOLS.

Frequently work is sent to the machine shop too large in diameter to be accommodated by the ordinary lathe of the largest swing on hand. One improvised method for handling this work, when special tools are not available, is to insert blocks under the head and tail stocks. The blocks are accurately planed and fitted to the shears to the desired elevation, thus giving the proper alignment, and within limits the required work can be performed.

Another method is by means of the *gap lathe,* in which a gap is cast in the bed just in front of the spindle, forming what is known as a *gap lathe,* and when the gap is not required it may be closed with a separate piece, closely fitting into the opening, and forming a flush bed. Another form provides for the same purpose in the *extension gap or break lathe,* Fig. 264. In this machine the bed consists of two separate parts, a base plate or bed, the full length of the machine, and an adjustable upper part or bed proper, which slides on the base plate. This lathe bed is carefully fitted to the bed plate, and may be brought up to the face plate, or to any desired distance from it within the range of the machine, by means of a rack and pinion and hand wheel. The carriage and tail stock are carried on the upper or traveling bed. The lathe may be used as a screw-cutting lathe, with or without the gap, and also as a *face lathe,* and the work is supported either between the centers or on the face plate. In other details the construction is similar to that of the regular screw-cutting and turning lathe.

There are frequently various occasions for a number of different operations upon similar pieces of work; for instance, the same piece of work may have to undergo the process of turning, drilling, reaming and facing, etc., and for each individual piece of work the time and labor consumed in the ordinary lathe, in changing from one tool to another, is costly. To obviate this loss a *turret head* has been arranged so as to be applied to the standard engine lathes,

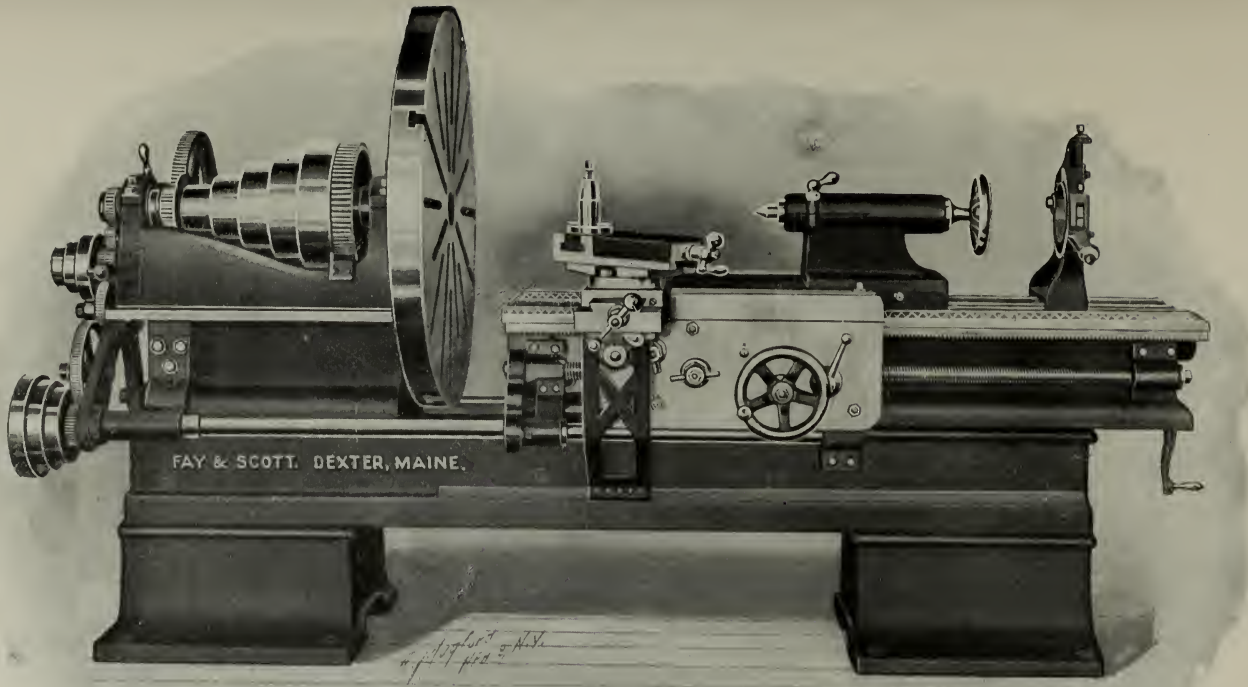


Fig. 264.

whereby these several operations can be performed by the turret head equipped with the several tools needed.

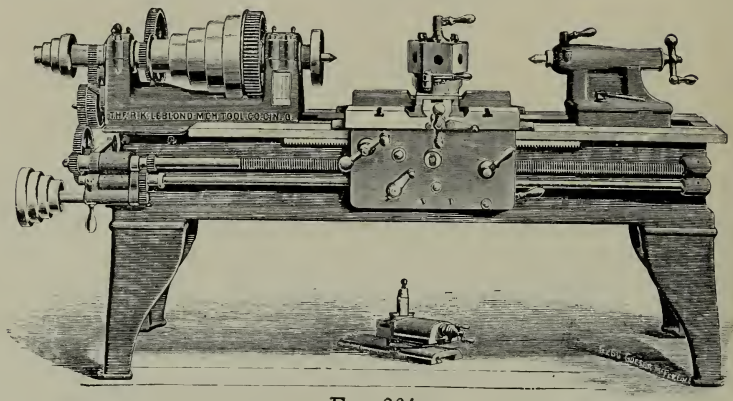


FIG. 264a.

As generally applied, Fig. 264a, the turret is usually circular or hexagonal, rotates about a vertical axis, and is interchangeable with

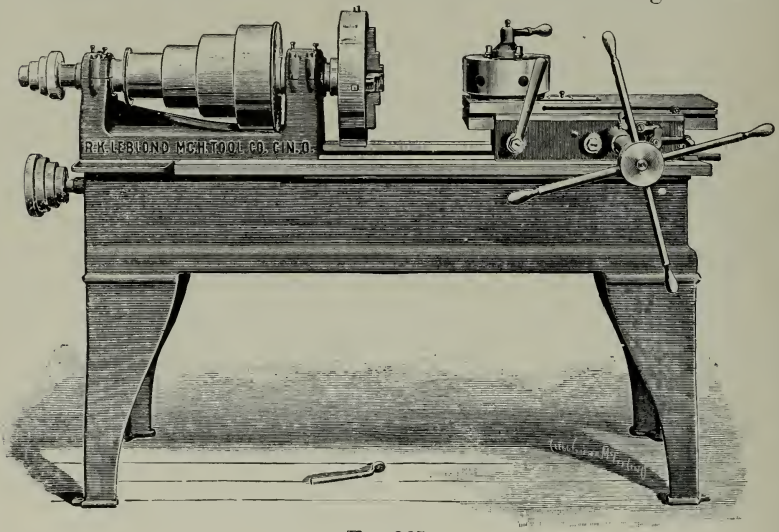


FIG. 265.

the compound rest; thus mounted on the carriage, it has the power traverse and cross feed of the carriage. With the different tools, drills, reamers, facing tools, hollow-mill taps, dies, etc., it may be

extensively used, both in chucked and bar work. Each tool is brought into operation by rotating the turret through a given distance, suitable mechanism being provided to locate the turret control with the spindle, and to regulate the rotation about the vertical axis.

Since a large amount of lathe work requires but a short travel of the tool, it may be chucked, and has given rise to an extension of the turret tool in the form of many automatic chucking machines, in which various operations are still further combined and performed automatically without changing tools or shifting work. The most elementary form of the plain *turret lathe* is shown in

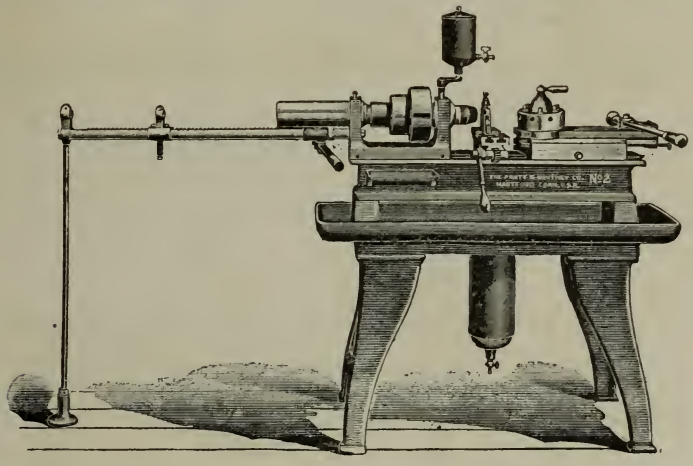


Fig. 266.

Fig. 265. The spindle has a hole through its center for bar work, the turret is automatic in its action, has six divisions for tools, and is fitted with a locking key. The turret revolves automatically and is provided with a lever to withdraw the locking key by hand, so that the turret may be worked at any point of its stroke, thus permitting the use of one or more tools, moving them back and forth, as the nature of the work requires.

Turret-Screw Machine.—This machine, Fig. 266, is of the general class of plain turret lathes, and is used for screw-making from the bar. It is fitted with a wire feed and chuck so constructed that the operator may feed the stock forward the required amount for

the operation, grip it in the chuck and when finished, release the stock in the chuck without stopping the lathe.

Other modifications of the lathe used for special purposes are *wheel lathes* and *pit lathes,* used for turning pulleys and balance wheels of large diameter; *pulley lathes,* in which the hub is bored at the same time the rim is being turned; *pipe-threading* and *cutting-off machines,* and *two spindle lathes* to take in work of large diameter without increasing the length. This is accomplished by placing one spindle above the other, the lower one fitted with a pinion on its nose and gearing into a large internal-geared face plate fitted to the upper spindle, thus obtaining a large swing for the upper spindle.

Drilling Machines.—The drilling machine consists essentially of a revolving spindle carrying the cutting tool, the base for supporting and securing the work, and a column and framework connecting the two. With the above parts are associated the various details of spindle feed, speed arrangements, method of drive and adjustment. The mechanical details and movements in accomplishing these results are varied and ingenious, while the specialties of the different makers show varied labor and time-saving adjuncts, in the way of tapping and reaming attachments and driving and speed improvements.

In Fig. 267 is shown a type of the *double-geared* drilling machine. The spindle is fitted with a cone pulley *A* and driven by the countershaft *B* in the usual manner. The rotating motion of the cone spindle is transferred to the drill by the bevel-gear wheels *C* and *D,* the former being secured to a sleeve *E,* fitted with a key on its interior neatly fitting a corresponding key-way cut in the spindle, and allowing the latter to move up and down through the sleeve during revolution or at rest. An enlarged view of the spindle and its attachments is shown in Fig. 268. On the lower part of the spindle is a sleeve *F,* on the outside of which a rack *H* is secured, and within the sleeve the spindle revolves freely. Collars *G-G* are secured to the spindle at the top and bottom of the sleeve *F,* hence the rotation of a pinion (*J* inside of frame) meshing with the rack *H* will raise or lower the drill spindle irrespective of its rotation, and thus governs the feed. Thrust plates *K-K,* consisting of two

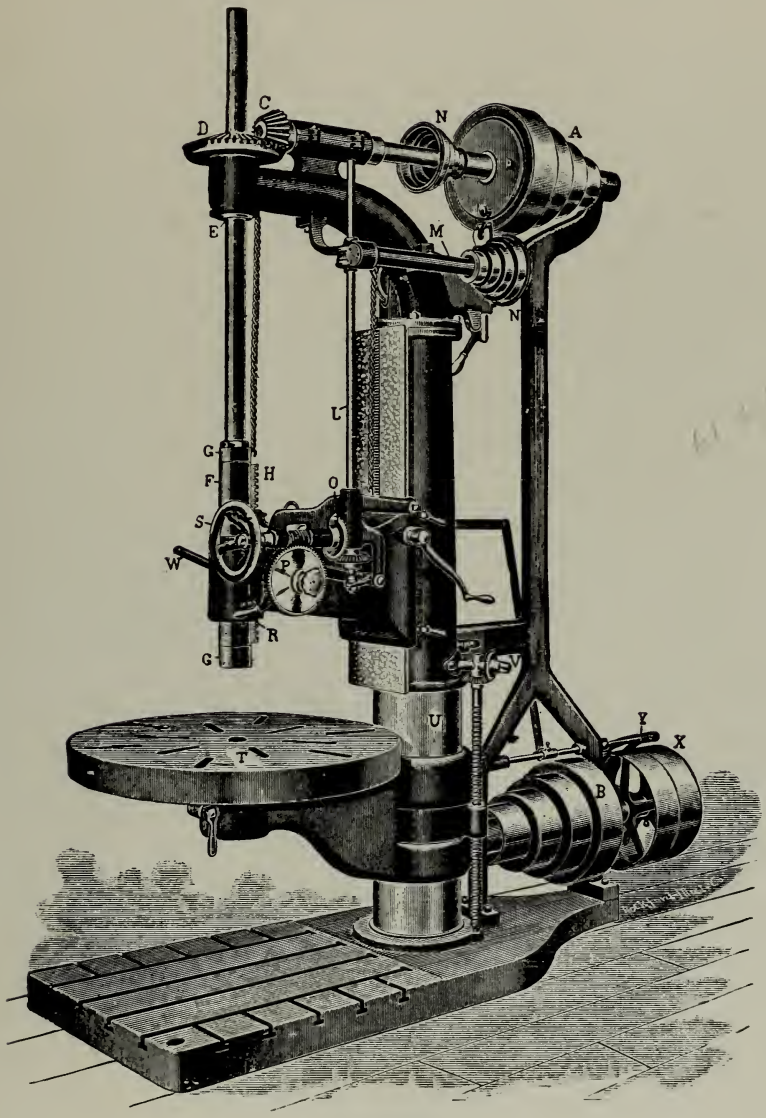


Fig. 267.

steel discs with one of brass interposed between, are fitted at the bottom of the sleeve, between it and the collar *G*. to take up the wear.

The Feed.—By means of the pinion and rack *H* the sleeve and spindle may be raised or lowered, and the feed given either automatically or by hand. The arrangement for the former consists of a small vertical spindle *L*, revolving by means of a worm wheel at its upper end in connection with a worm on the end of the horizontal shaft *M*, driven by the small cone pulleys *N*-*N*. The motion of the revolving spindle *L* is transmitted to the pinion and rack on the drill spindle sleeve by means of the bevel gear *O* and worm-wheel gear *P*, the worm wheel revolving on a horizontal shaft to which is secured the pinion *J*, and the worm wheel may revolve loosely on this shaft or be secured to it by the clutch wheel shown in front. By securing the clutch the drill spindle has a regular feed as long as the machine is in operation, and which can be varied to the extent of the variations in the cone pulleys *N*-*N*.

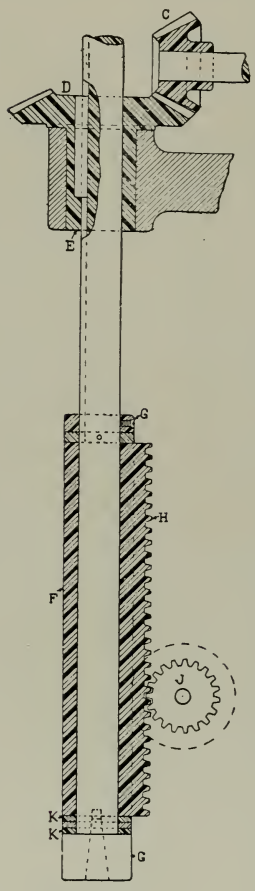


FIG. 268.

To feed by hand, the bevel wheels *O* are thrown out of gear by means of a small lever *R* (partially hidden behind the worm wheel *P*), the worm wheel *P* unlocked from the pinion *J* by the clutch wheel, and then the spindle operated directly by hand with the hand-feed wheel *S* through the pinion *J* and rack *H*. The lever *W* gives a lever feed, directly actuating the drill spindle.

The table *T* is secured to an arm projecting from a sleeve on the column *U*, and is fitted with slots for securing the work, as in the face plate of a lathe. There are numerous methods for the vertical adjustment of the table: in this case the table is moved vertically by means of a screw working in a nut on the side of the sleeve and operated by the handle *V*; the screw bottoms on a collar at the base of the column, and thus permits the table to be swung around the column, leaving the base plate free for larger work.

This machine is of the type known as a *sliding-head* machine, the column being fitted with a wide face for securing the sliding head, which is counter balanced by a weight inside the column attached to the head by the chain shown. The head is fitted with a clamping device by which it can be held firmly in any position on the column.

The counter-shaft is shown at the base with the fast and loose pulleys at X driven from the main shaft, the belt being shifted from one to the other by the fork and lever arm Y.

The back gear may be arranged in the same manner as on a lathe, that is, the cone pulley riding loosely on the cone spindle, and for double gear, throwing in the back gear, as described under the head of the screw-cutting lathe, or in the machine under discussion by means of internal differential gearing within the cone pulley, shown in Figs. 269 and 270.

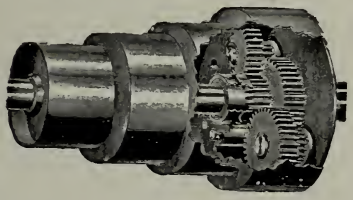


Fig. 269.

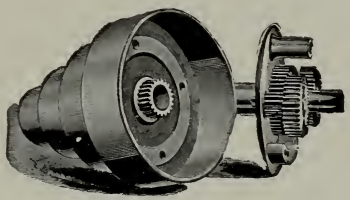


Fig. 270.

The single-geared drilling machine is clearly shown in the illustration, Fig. 271. The back gear of the preceding drill is dispensed with, and the cone pulley is connected directly to the cone spindle. Instead of a sliding head, this machine has a stationary head, the feed of the spindle being limited to its available length, and the vertical adjustments are given by the table. The spindle operating gear is similar to the back-gear type just described. The table is adjusted vertically on the column by means of a worm gear in connection with a rack and pinion on one side, and is secured at any height by means of the clamping screw shown.

Slot Drilling, or Splining Machines.—These machines are principally employed in cutting slots, keyways, etc., although much of their work is now largely performed on the milling machine. The drill spindle is carried along a straight line as it rotates, due to its connection to a sliding piece on a fixed saddle.

Radial Drills.—This type of vertical drilling machines possesses many facilities for drilling vertical holes in large objects, not readily moved, by adjusting the drill over the work instead of arranging the work under the drill, as in the machines we have thus far been

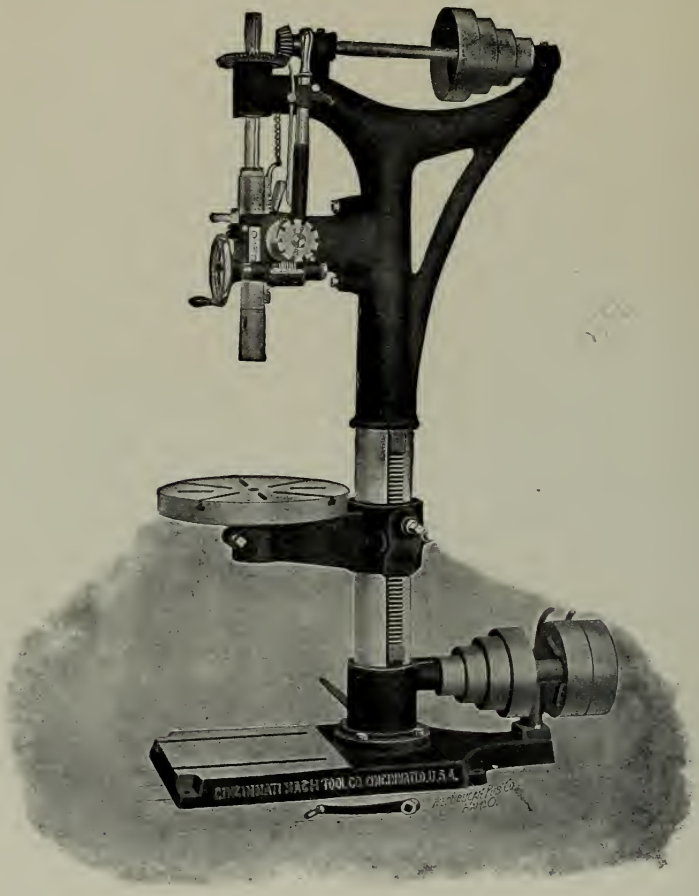


FIG. 271.

considering. This power of adjustment is obtained, as seen from the illustrations, by supporting the drill spindle with its gearing and mechanism, upon a carriage, which can travel horizontally upon a radial arm, the arm itself being capable of revolving upon the

central column. By a combination of the travel of the slide with the circular motion of the arm, the drill can be made to cover the entire area, due to the extreme radius of the drill spindle beyond the column. In addition to these two movements, the radial arm has a vertical power adjustment on the column, giving a considerable range to the rise and fall movement of the radial arm.

In obtaining these advantages, simplicity in the working mechanism is sacrificed to some extent, as is the case with most of the modern machine tools fitted with automatic devices for saving time

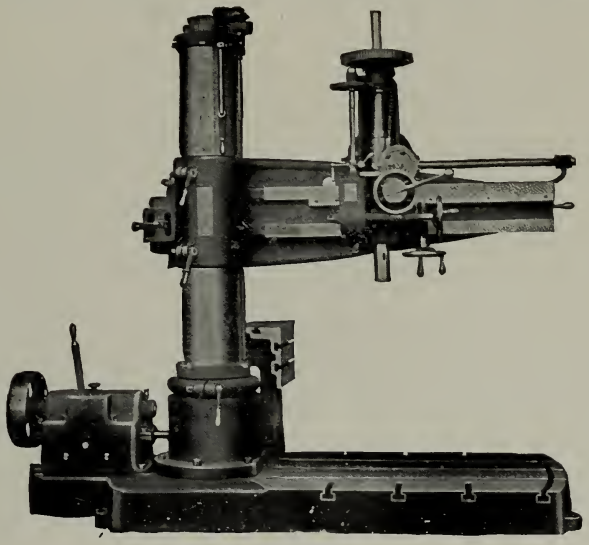


Fig. 272.

and labor. This is evidenced from the conditions that the power must be transmitted through bevel and spur-wheel connections and various shafts; in the case of the radial drill, from the horizontal cone-pulley shaft, at the left in Fig. 272, to the outer vertical column or sleeve, thence to the horizontal radial arm whose height and direction are variable, then with another change in the vertical direction to the upper head of the carriage and to the upper end of the drill spindle. In the absence of numerous detailed illustrations which are not practicable in the time allotted, the illustration of the typical examples of modern machine tools in the Engineering Building should be examined in conjunction with the text-book.

Radial drilling machines are of three classes, viz.: *Plain, half universal,* and *full universal.* In the plain pattern the head works vertically in any radial plane parallel to the radial arm; in the half universal the head and spindle are mounted so that they will swing

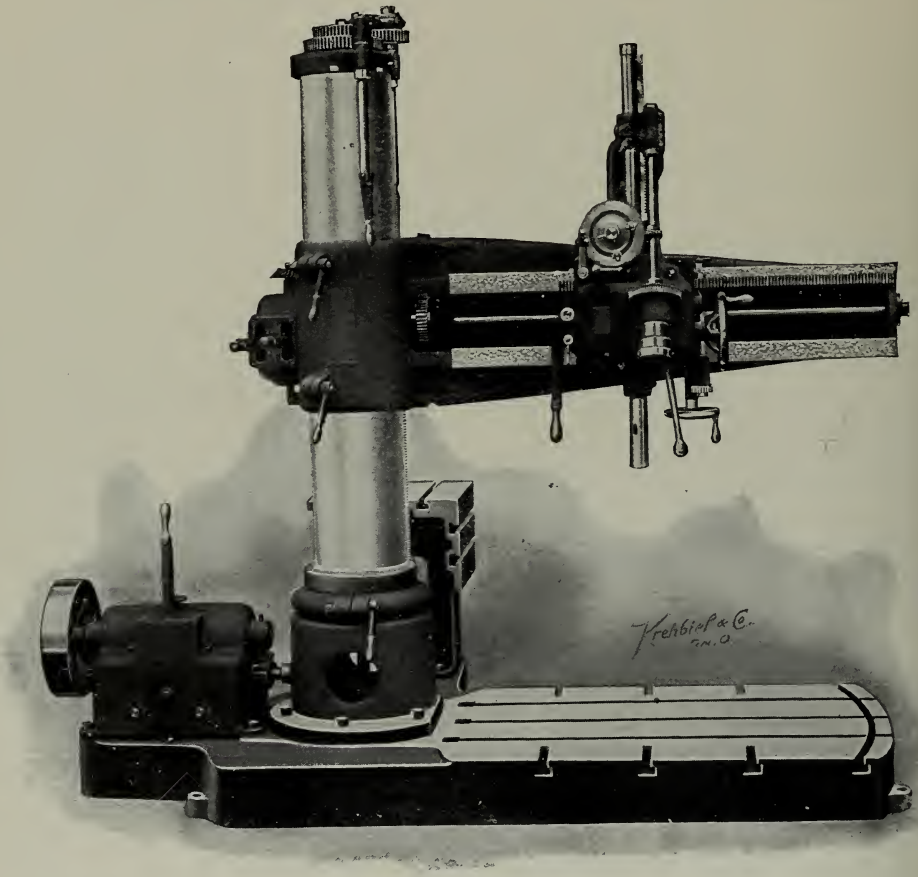


FIG. 273.

at all angles in a vertical plane and drill accordingly, while with the full universal pattern the head works at all angles, radiating from the center of a sphere, thus making it possible to drill holes at any inclination or direction with the base. These three types are shown in Figs. 272, 273, and 274. Referring to the plane radial

drill, Fig. 272, the upright consists of two parts; the outer part or column is a sleeve mounted on a stationary stump, which extends up to and has a bearing at the top of the machine, and is equivalent to a double column, thus furnishing the stiffness essential in a machine of this shape. The outer column or sleeve rotates upon this stump and can be secured in any position by a V-shape clamping ring. The radial arm is raised and lowered by power, is easily swung around and clamped. The back gear is located in the back of the head and may be readily disconnected by the lever in front of the head. The spindle, through appropriate mechanism, has

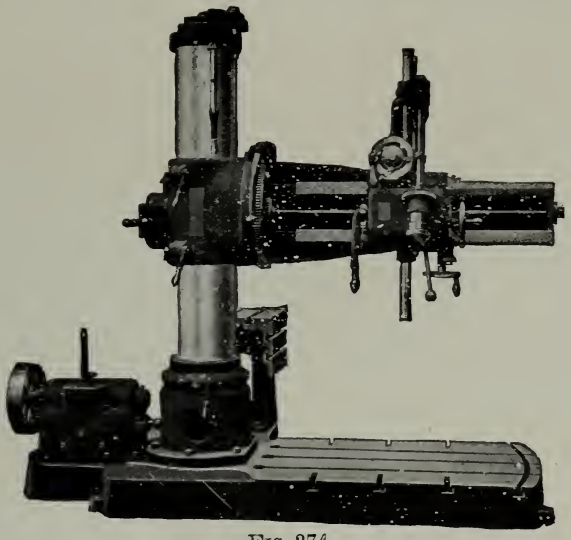


Fig. 274.

both hand and power feed, quick advance and return, safety stop and hand-lever reverse, and with ample speed changes. Tapping mechanism is incorporated in the design of the head, so arranged that the taps may be backed out at any speed regardless of the speed used in driving them in, the movement being controlled by a friction clutch at the head.

Sensitive Drilling Machines.—High speed is required for small drills, and to obtain this speed very light parts are used, forming what is known as a *sensitive drilling machine*, that is, one in which the progress of the drill is felt as the feed progresses. This is

quite an advantage, especially when drilling small and accurate work, and of considerable importance when the point of the drill is about to pass through the work. There are a number of different varieties of sensitive drills in common use, and generally the drive is without any wheel gearing and the feed is actuated by hand. In Fig. 275 is seen a type in general use with a friction drive and individual motor, the speed of the spindle being adjustable by moving the driver to, or away from, the center of the driven friction disc. The feed is given by the lever in front, directly actuating the drill spindle. There are but few parts, and this, with the method of the drive, insures the smooth running necessary for fine work.

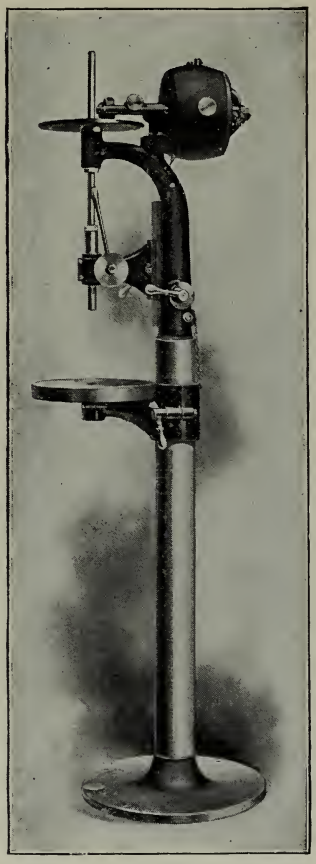


FIG. 275.

Multiple Drills.—These drilling machines were devised to drill a large number of holes with the greatest rapidity and with accuracy necessary to insure perfect correspondence between the holes, for use in such operations as plate and girder work, or machine work, such as chest covers, where a number of parallel holes can be drilled at once without changing or setting the work. In Fig. 276 is shown one type of the multiple drill, consisting of a number of vertical drilling spindles driven from one horizontal main spindle shown above the rail. The rail is supported by housings placed sufficiently far apart to take in the largest size work in the class to be operated upon. To enable the holes to be drilled at any required points and desired distances apart, the heads are adjustable on the rail and may be

used independently or collectively as desired, each head being complete in itself.

These drills are fitted with the usual arrangement of feed changes, hand and power feed, etc. The horizontal driving spindle

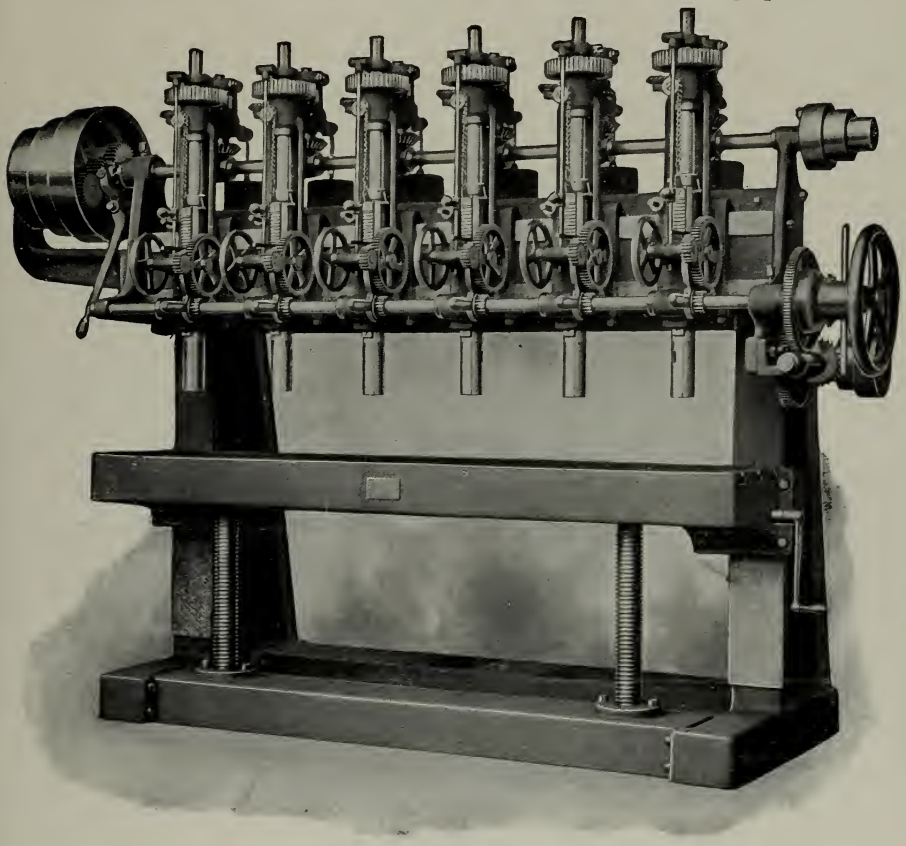


Fig. 276.

is connected at one end to the cone pulley with back gears for the decrease of speed and increase of power, located inside the cone.

Gang Drills.—These machines are composed of distinct drills, each of which is complete in itself, but on a common base, and drills may be detached and operated as separate tools whenever occasion requires. As with other special tools, the economy of the

multiple and gang drills consists in being supplied with work on which they may be used advantageously, as, for instance, in boiler plate, bridge or structural work, etc.

The Ratchet Brace.—A useful example of a portable drilling hand tool is the *ratchet brace,* Fig. 277. The ratchet wheel *A* is fixed to the drill spindle, the wheel being driven by a pawl *B,* as the

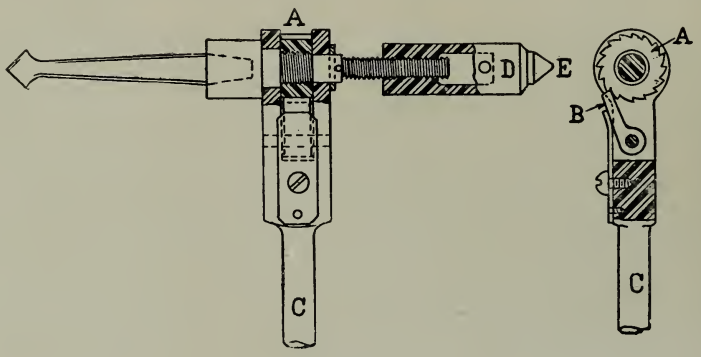


FIG. 277.

handle *C* is drawn towards the operator. On the back stroke the pawl slips over the teeth and obtains a fresh grip on the next stroke. Feed is given by holding the sleeve nut *D* by one hand, and turning the ratchet right-handed, the drill spindle thus receives a downward movement. This tool is quite valuable in general fitting and erecting work, as it can be used for drilling holes in awk-

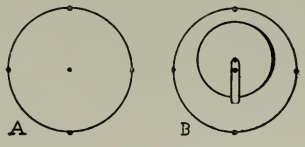


FIG. 278.

ward places where a power drill could not be employed. It is compact and light, and can be readily rigged up wherever a plate or a support can be obtained to receive a center punch mark or hole, into which the center *E* of the brace may be located.

Centering.—In drilling holes, the location of the center is indicated by a center punch mark into which the point of the drill

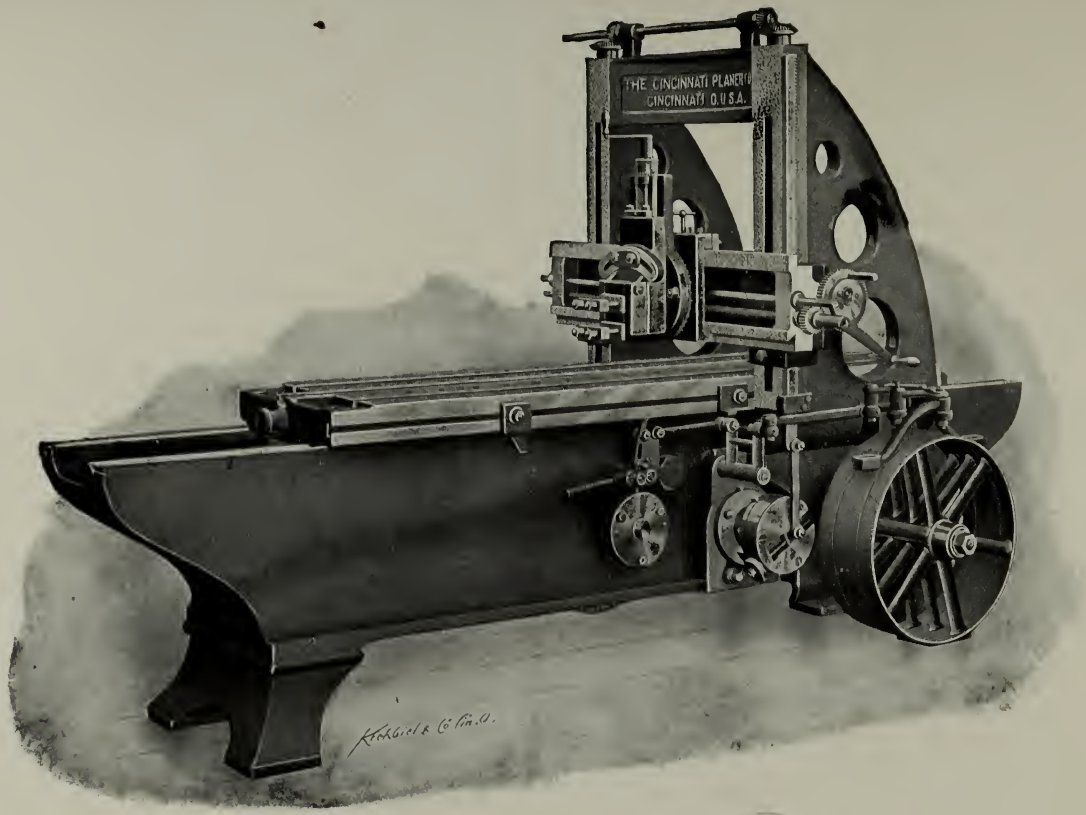


FIG. 279.

starts. If any accuracy is desired, a circle equal to the diameter of the drill is described about the center punch mark as a center, and a few light prick punch marks made on the circumference. The work is set as truly as possible to the circle. As the point of the drill penetrates the metal, the circle cut should be closely watched, and if it is not concentric with the scribed circle, it should be corrected by chipping a groove with a round-nose chisel at a point in the circle directly opposite to that to which the drill has moved from the original center. The *groove should reach the root or bottom of the hole,* and must be done *before the drill begins to cut its full diameter.* This chipping is done simply to give a new and correct center for the drill to enter, and it is apparent that it would be ineffective after the drill has made a hole equal to its own diameter.

The Planing Machine.—Like the lathe, the planing machine is essentially a copying machine, and produces a close approximation to a plane surface by making a series of parallel cuts with a tool, each cut as to direction, being an exact copy of the slide which determines the nature of the movement of the platen under the tool. The line of direction of each succeeding cut is also a copy, in this case, of the cross slide along which the tool receives its feed motion. Both these movements take place in straight lines, since they result from plane surfaces sliding upon one another, hence every part of the work upon which the extremity of the tool is made to act lies in the plane surface.

An example of the ordinary planing machine is given in Fig. 279, and consists briefly of two parallel beams forming a part of the bed, having upon their upper surfaces V-shaped grooves cut accurately parallel along their length and with truly planed sides. On these slides work a reciprocating, rib-stiffened table, on which the work is supported and secured, its surface being cast with T grooves to receive clamping bolts, and on the under side cast with V-shaped projections fitting the grooves in the bed and carefully worked up to a true surface.

Two uprights or standards, bridged at the top by a *cross rail* or *tie bar,* are secured on the sides of the bed, the face of each upright being planed and scraped to a true surface. Down the center of each face a groove is made, and within each is a square-threaded

vertical screw, having at the top a bevel-wheel gearing with a similar wheel on a horizontal shaft. Beneath the cross rail a horizontal *cross slide* is fitted, supported by the vertical screws just mentioned, the slide being fitted with long nuts at its back, and thus capable of being moved vertically to any position by means of wrenches on the horizontal bevel-wheel shaft mentioned above. After adjustment to the proper height, it is clamped in position by set screws. The cross rail carries one or more tool heads with their cutting tools so arranged as to give a vertical feed, cross feed, or an inclined feed to the tool. In the illustration two light shafts may be seen running from end to end in the cross slide, one with screw thread cut upon it and engaging with a nut on the tool-head saddle, by which means the tool head is fed horizontally along the cross rail. Par-

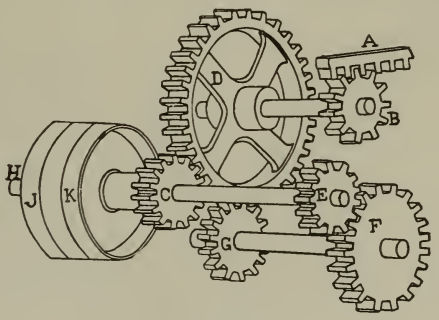


Fig. 280.

allel to this screw shaft is a shaft fitted with a longitudinal groove for a feather on a bevel gear, and through which a vertical motion is given to the tool head by gearing to the *vertical feed screw*. By these means the cutting tool may be moved horizontally and vertically through the cross slide and tool-head saddle, respectively, and the motion may be given either by hand or automatic action.

Movement of the Table.—The reciprocating motion of the table is effected by means of a rack cast in the center of the table on its under side. Into this rack gears a pinion driven by a train of wheels arranged for speed reduction, and the ordinary belt and pulleys. As no work is done on the return stroke, a quick return must be arranged, and as usually applied to planing machines is shown in Fig. 280. The rack is shown by a short section at *A* and

gears with a pinion *B*, which is connected through the train of wheels shown, to the shaft *H*. This shaft has three pulleys upon it, the left-hand pulley *J* is for the cutting stroke and is fixed to the shaft; the center pulley is an idle pulley and rides loosely on the shaft; pulley *K* is connected by a sleeve to the pinion *C*, but rides loosely on the shaft and is geared for the quick return. In its operation, the belt being on the pulley *J*, motion is transmitted by the shaft to the rack through the pulleys *EFGDB* with the reduction due to the gearing. When the belt is on *K*, motion is transmitted by the pinion *C* and its sleeve directly to *B*, the direction of motion of the rack being reversed and an increased speed obtained. Hence, to obtain reciprocation at proper intervals, all that is necessary is to shift the belt from one of the outside pulleys to the other at proper times. This can be done by merely moving to one side or the other the projecting lever near the center of the table, and this can be made self-acting as follows: At rest the belt is on the loose middle pulley and the handle at right angles to the bed, the driving belt passes through a *strap fork*, which is connected by levers to this handle, so that as the handle is moved in one direction the belt is thrown over to one of the live pulleys and, if it is moved in the opposite direction, the belt is dragged over to the other pulley. To make this movement automatic after starting, if the table is moving to the left, an adjustable stop on the right-hand end of the table, will at the point of the stroke at which it is set, strike the arm or lug in connection with the starting handle shaft, thus turning it, and through the connecting levers the strap fork is drawn across, carrying the belt with it, to the other live pulley, and thus reversing the table. On travelling to the right a similar movement takes place, the stop on the left-hand half of the table strikes the lug on the starting handle shaft and the belt is carried back to the other pulley with a reversal of motion as before. We have now accomplished two requisites of a planing machine, viz., a reciprocating motion for the table and a slow advance and a quick return.

For the feed, the same mechanism usually operates both vertical and cross feeds. With the varying travel given to the bed at different times, the mechanism must be designed to give the same or a constant feed motion for a short stroke of the table, as well as for

its extreme travel. A feeding device largely used consists of an extension of the rack-pinion shaft terminating in a disc *A*, Fig. 281, secured to the end, and which rotates to the right or left in accordance with the movement of the table. A cylindrical casing *B*, with a cover *C*, surrounds the ends, with friction washers *H* on either side of the disc, the cover being held up to the casing against the friction washers with a uniform pressure, by the studs *D*, *D*, *D*, fitted with spiral springs under their nut. *E* is a wrist pin secured to an adjustable slide on the cover *C* and may be secured at any point on the diameter of the cover. The nuts are set up and the pressure adjusted so that as the pinion shaft moves, the casing, cover and wrist pin all rotate, but if at any point the casing is held, the disc will slide between the washers, the casing, cover and

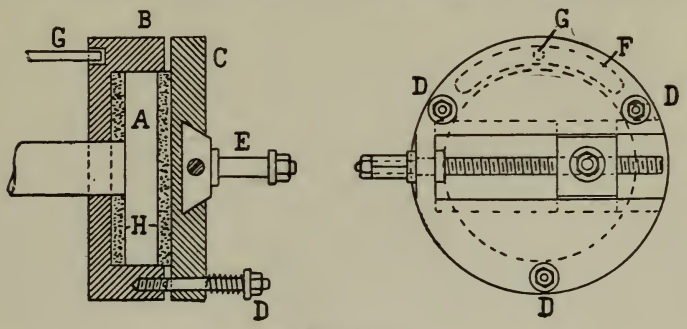


Fig. 281.

pin remaining stationary. A circular groove *F* is cut in the back of the casing to receive a stationary pin *G*. The wrist pin is connected to a rack at the side of the planer, which meshes with gear controlling the feed on the cross slide.

In operation, the table is started and *A* and *B* revolve, carrying the rack up or down depending on which side of the center the wrist pin is, and this movement is continued until the pin *G* strikes the end of the slot when the casing and wrist pin remain at rest, while the disc *A* revolves between the friction washers until the table has completed its stroke. On the return stroke the rotation is reversed, the disc, with the casing cover and wrist pin, all rotate in the opposite direction until the pin *G* strikes the opposite end of the slot, motion in the meanwhile having been given to the

rack in the opposite direction to that received previously. Thus, for each stroke of the table, the rack receives a movement constant in amount, up or down, which is transmitted to the tool head through appropriate mechanism in the cross slide, and the amount of this movement can be regulated by bringing the pin nearer to or away from the center of the cover *C*.

Planer Tool Head.—In Fig. 282 the different parts of the *planer head* are seen. The saddle *A* travels upon the *cross slide B,* to which it is securely gibbed, and at the center of the saddle is pivoted the *swinging frame C,* so that the *tool box* may be inclined

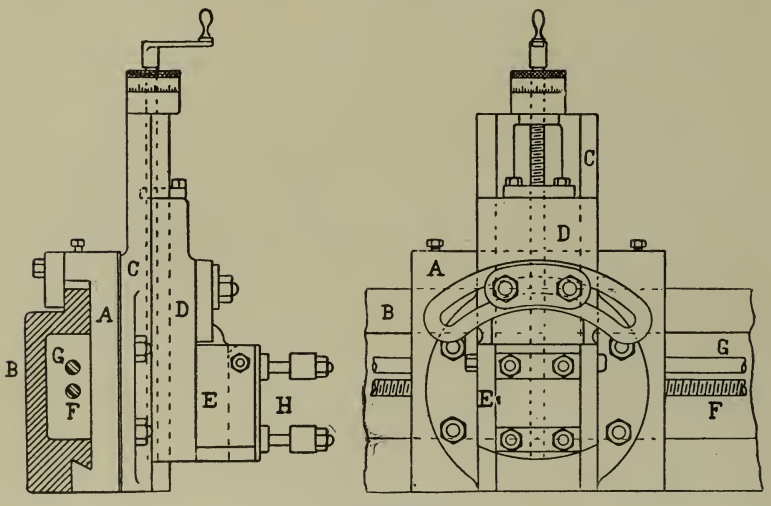


FIG. 282.

to one side or the other from the vertical, and clamped in any desired position by a bolt passing through a slotted hole in its upper part. To the swinging frame is gibbed the *slide D,* and is operated by the feed screw either by hand or self-acting as required. The tool box *E* is pivoted to the slide, permitting adjustment on each side of the center and clamped by bolts. Finally, the *apron* fits within the tool box and is pivoted to it at its upper end, thus permitting the tool to swing outboard as the return stroke is made, and prevents the work being marred and the tool injured by dragging over the surface. To the apron is secured the tool post *H*. The

vertical feed is given through rod *G* and the horizontal feed by the rod *F*.

The Open-Side Planer.—A modified form of the planing machine, known as the *open-side planer,* in which one housing is omitted completely, is shown in Fig. 283. In this machine the cross rail is

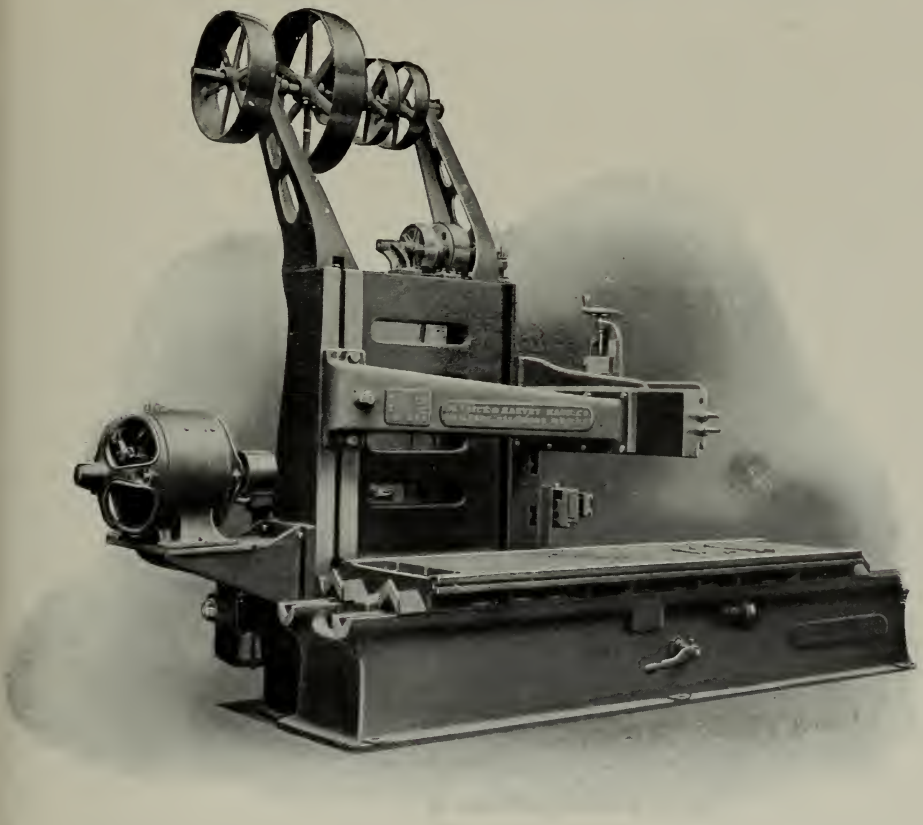


Fig. 283.

necessarily very strongly braced, and the housings supporting it on one side only, must be more massive than in the preceding tools. This machine is designed for very large, wide work, or irregular castings which could not be conveniently machined within the limits imposed by the standards or housings of the ordinary planing machine.

The Shaping Machine.—The shaping machine, while employed for work similar to that of the planer, that is, the planing of surfaces by straight line cuts, differs largely in the design. With the planer the work moves while the tool is stationary and the cross and vertical feeds are given by the tool. With the shaper the reverse of this is the case, the work is stationary while the tool moves in cutting and the cross feed is operated by the work, the vertical feed only being given by the tool.

Shapers are used in preference to planing machines when short pieces of work are to be planed; they take up much less room and the work can be put in, taken out, and the machine and work handled more rapidly than with a planer.

Shaping machines are made in two general types, those in which the ram is moved by a rack and gear drive similar to that by which the table of a planer is actuated, and the crank drive, in which the ram is actuated through a crank or its equivalent, and an appropriate system of gearing. A design of the latter is shown in Fig. 284, in which the upright base is called the *column* and to which a *cross rail* is gibbed to the front face and arranged for vertical adjustment by an *elevating screw*. The projecting heavy casting in front of the cross rail is called the *box or knee*, and is secured to a *saddle* which moves over the cross rail. This box is cast with T slots on the top and sides for supporting and securing the work. The tool head is similar to that employed for the planer and is fixed at the end of the *ram*, the reciprocating part or sliding head at the top of the machine, working in a gibbed frame on the column top. The *swinging frame* is pivoted to the end of the ram, rotation of the same being effected by means of a worm gear and hand wheel, enabling it to be operated for concave surfaces while the machine is in motion.

From a consideration of the movement of the crank and connecting rod or link, it can be seen that the relative velocity of a ram at the end of the link varies greatly between the beginning and the end of the stroke, also that the return stroke is made at the same rate as the forward or cutting stroke, both of which are inadmissable in quick-working, time-saving, modern tools similar to the shaper. Hence, the simple crank drive has been superseded in the different forms of shapers of the several makers, by some form of

crank drive involving a quick-return motion, to save time on the idle stroke, and also to equalize, as far as practicable, the velocity of the ram at different points of the stroke.

In the crank shaper, shown in Fig. 284, the motion governing the ram is produced by a cone pulley, carrying on its shaft a small pinion, transmitting motion to a spur wheel, within the column, and on the axis A, and mechanism corresponding to what is known as the *slit-bar quick-return motion*. The line sketch in Fig. 285

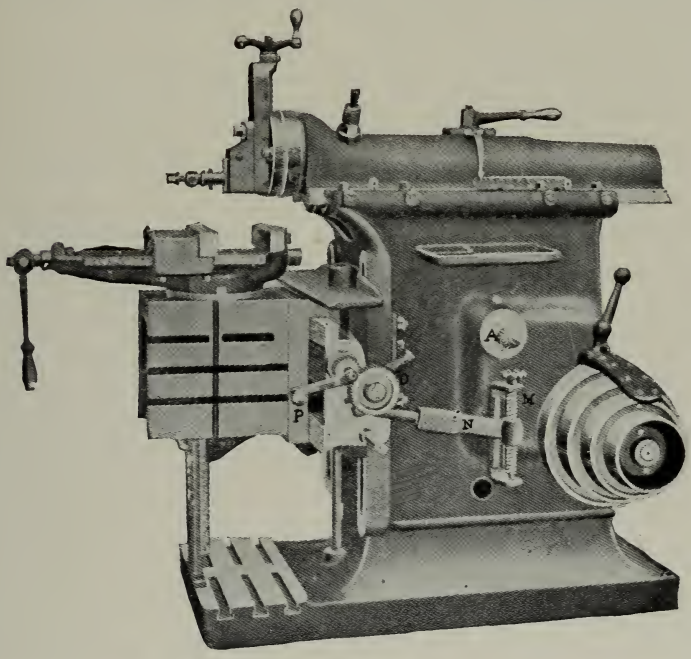


Fig. 284.

shows the arrangement of this motion in actuating the ram. B is the pinion driven by the cone pulleys and meshing with the spur wheel C. The crank pin is at D, and works in a block, movable in a radial slot E, the radial distance of the pin D being adjusted by means of bevel gear and a screw operated by a crank attached to the end of the shaft on axis A, Fig. 284. A slotted bar F, engaging the pin D, is pivoted on the base of the machine at G, while its opposite end is linked to the ram of the shaper at H. As C turns

the end H of the slotted bar moves back and forth in a horizontal arc, the connecting link causing the ram to move in a horizontal line forward and backward, the velocity ratio of the two strokes varying as the arcs $\frac{DJD^1}{DKD^1}$, and thus giving a slow forward movement while cutting, and a quick return of the ram on the idle or return stroke.

For a mathematical demonstration of the exact velocity ratio of

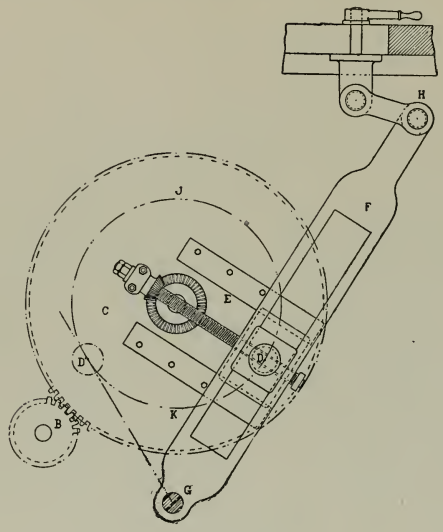


FIG. 285.

the forward and return strokes, see the text-book on *Elements of Mechanism,* Circular and Reciprocating Motion.

Automatic Cross Feed.—This is obtained by means of threaded nut M, Fig. 284, having a vibrating motion, due to a bell-lever connection within the column. This reciprocating movement is transmitted by means of the link N to a pawl and ratchet O and adjacent gear wheel, to a pinion on the end of the horizontal feed screw acting in a nut on the back of the saddle.

To operate the saddle by hand, the pawl is disconnected and the feed screw operated directly by the handle P.

The vertical feed is by hand by means of the feed wheel and

slide on the tool box. For large-sized machines, arrangements are made for automatic feed vertically.

The vise attachment shown can be swung around at any horizontal angle, the lower base plate of the vise having a circular graduated index.

There are a number of methods of producing a quick-return motion for the ram of a shaping machine, one method very widely known being that invented by Whitworth, Fig. 286. Its action is as follows: A spur wheel *A* revolves freely upon a shaft *B* of large diameter and is driven by the pinion *C* on the cone-pulley shaft. A hole *D* is bored in the end of the shaft, eccentric with its center, and serves as a center of motion for a crank piece *EF* fitted with

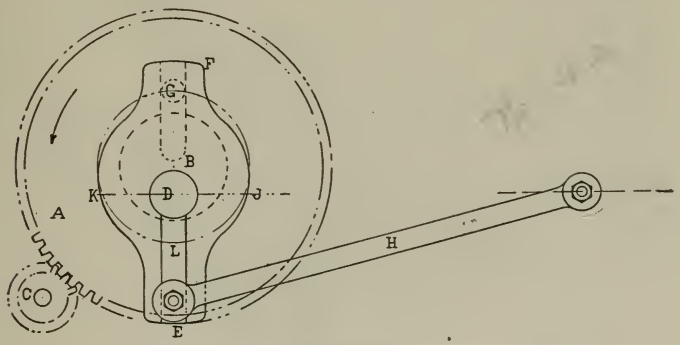


Fig. 286.

a pin to the hole *D*. With this arrangement the spur wheel and crank piece can each revolve independently but eccentric to one another; but by slotting the crank piece *EF* (shown in dotted lines) and fitting a pin *G* to the face of the spur wheel, they will revolve together, but the velocity of the crank varies as the driving pin *G* and the carrying pin *D* approach and recede from each other. By slotting a groove in the face of the crank piece and securing to it a connecting rod *H*, with the other end connected to the ram of the shaping machine, advantage is taken of this varying velocity of the crank to produce a slow advance and quick return, the period of advance and return being as the arcs *JGK* and *KLJ*. The stroke of the ram can be regulated by moving the adjustable fastening at the crank end nearer to or farther away from the center.

Rack and Gear-Driven Shapers.—A machine of this type is illustrated in Figs. 288 and 289, and has the following features: The quick return is effected by carrying on the counter-shaft, Fig. 287, in addition to the ordinary tight and loose pulleys for driving, two pulleys connected by belting to the machine, the larger one carrying a crossed belt which gives the quick return to the ram, the other is a cone pulley, smaller in diameter and with two steps to vary the speed of the cutting stroke. A small pinion on the pulley shaft engages the spur wheel *A*, Fig. 288, whose shaft within the interior of the column drives the ram by means of a pinion and rack, as in the planer.

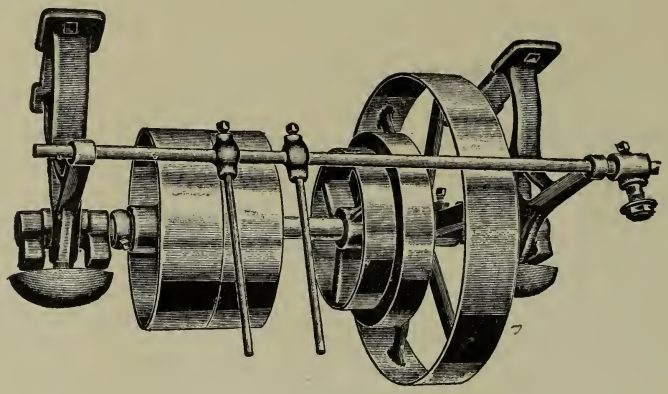


FIG. 287.

The Drive and Reversing Mechanism.—The drive is by means of a *friction clutch,* consisting of discs alternately embracing one or the other of the forward or backward pulleys which ride loosely on the pulley shaft, and giving the ram the corresponding movement. The alternation in the grip is accomplished by a vertical rod *B,* Fig. 289, with an arm at either end forming a bell crank shaft, the upper arm of which is struck alternately by two adjustable stops *C-C,* on the ram as it moves back and forth, thus throwing the lever arm to one side or the other. A light horizontal rod connected to the lower arm leads to and throws the friction grip from the forward to the backward pulley and vice versa, thus giving the ram the motion desired. The length of stroke is governed by means of the adjustable stops *C-C.*

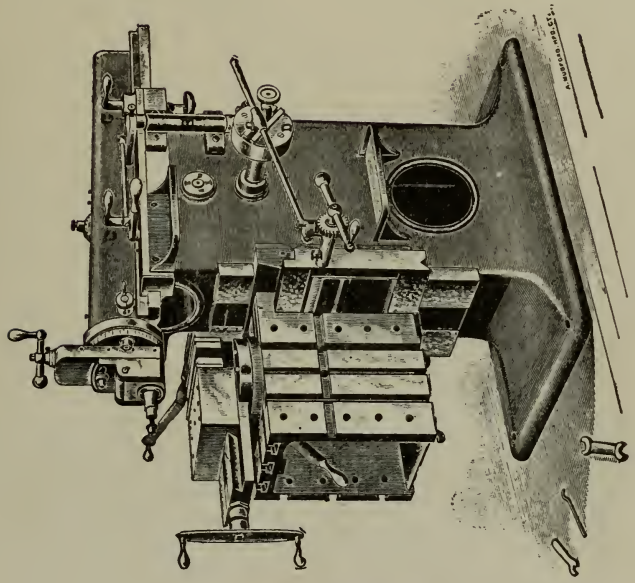


FIG. 289.

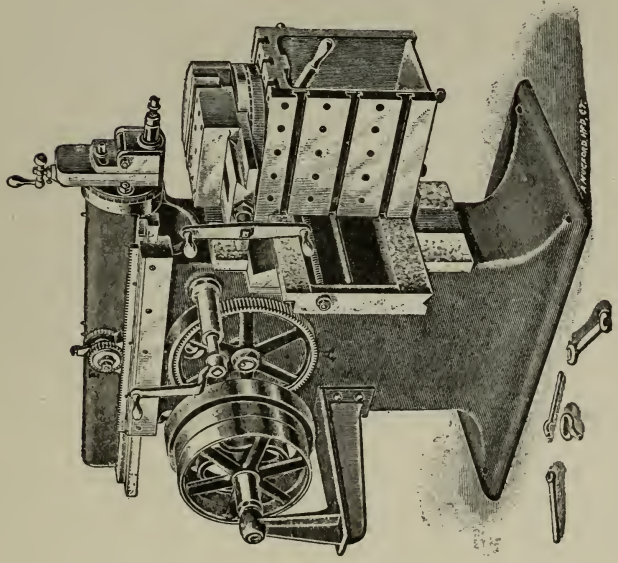


FIG. 288.

The Feeding Arrangement.—The horizontal feed is practically identical with that of the planer previously described, the friction disc *D* being attached to the ends of the spur-wheel shaft, and its reciprocating motion transferred by a rod to a ratchet wheel on the end of the feed screw *E*. Hand feed is given by disconnecting the pawl and turning feed screw by means of the handle on its end.

The vertical automatic feed is given by a pinion *F*, working on a shaft on the ram, and which meshes with a rack on its frame. Motion is transmitted from this shaft to the vertical feed screw by a system of rods and bevel gear within the ram.

Planing and Shaping Tools.—The tools used in planing and shaping, Fig. 290, bear a close resemblance to one another and, with the exception of a few, especially adapted to planing operations, are

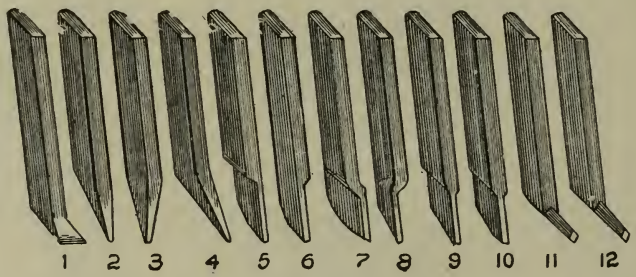


FIG. 290.

very similar to those used for turning. They are generally ground with but little bottom clearance, while the amount of rake given is largely governed by the hardness of the metal to be operated upon.

Properly equipped with the necessary attachments designed for the machines, the planer and shaper are capable of a wide range of special work, such as plane grinding, milling work, planing concave, convex, or circular surfaces, and with spiral planing attachments for work, such as the grooving of spiral rolls, interior keyways, etc.

In the varied operations performed by the planer and shaper, the setting and securing of the work is a matter of extreme importance and usually requires more mechanical ability than the machining itself. For large work, or work intricate in form or very light, unless care is used in setting and clamping, springing and distortion

is very likely to ensue; for this reason the supports should be heavy and bear as equally as possible between the table and the work.

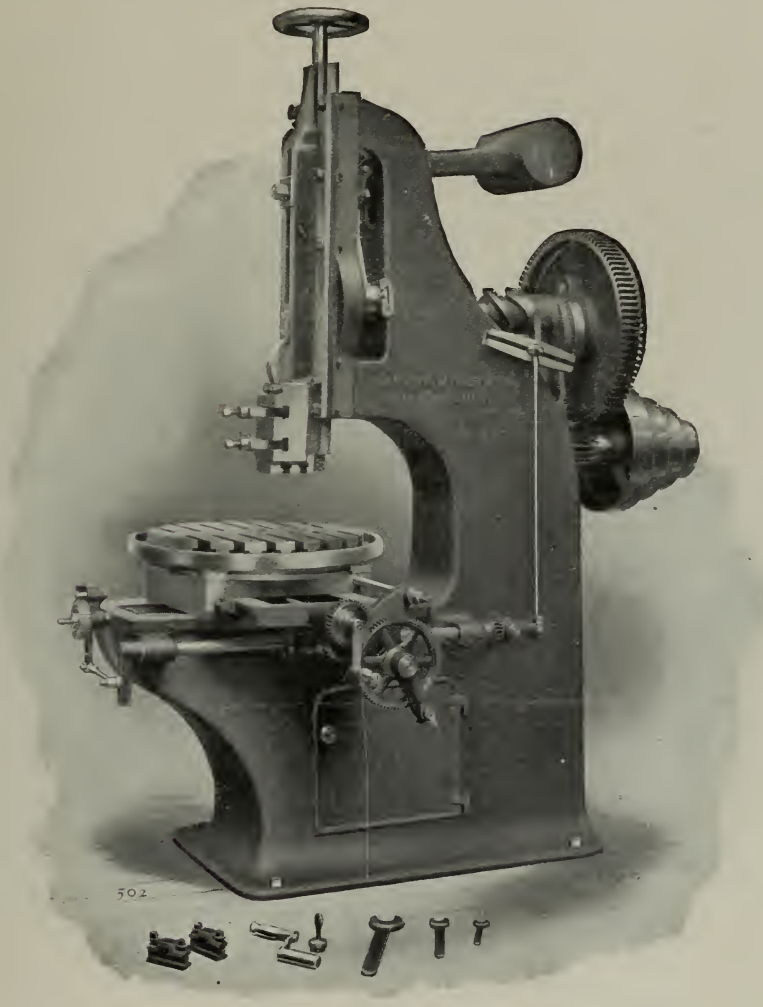


Fig. 291.

The Slotting Machine.—In principle this machine differs but little from the shaping machine just discussed, the slide giving motion to the tool, being merely placed vertically instead of hori-

zontally. In practice, however, much difference is found to exist between them in appearance, their design, and in their proportions, for the slotter may be amongst the heaviest tools in the shop.

The slotting machine is largely employed for slotting grooves in wheels, such as key-ways in hubs, and in addition they are used for almost all the paring and shaping which is required in the treatment of heavy work of rectangular or irregular outline, and which can not be readily done on the shaper or planer. Connecting rod ends, crank eyes, and rounded joints are familiar examples of the character of the work done in the slotting machine.

One form of slotting machine is shown in Fig. 291, and consists essentially of three parts, a heavy substantial casting constituting the *frame,* the *ram* carrying the tool head and cutting tool, and the *table* for supporting the work. The ram works vertically between two slides and has a quick return reciprocating motion. The table is in three parts and is capable of receiving three separate horizontal movements, the upper or circular parts being pivoted to a slider and can thus rotate about that axis; the slider works on the face of the saddle with a motion at right angles to the knee of the frame, while the saddle is gibbed to the knee and can move along the knee. By these movements, and with proper attachments, three feed motions are obtained—circular, transverse, and longitudinal—each of which may be worked automatically or by hand.

Method of Communicating Motion to the Ram.—The ram is connected to a circular crank plate on the front head of the machine by means of a connecting rod, the crank plate receiving its motion through the cone pulley and gearing shown in the cut; the crank pin is fixed in a block, adjustable in a radial slot on the crank face, and the stroke of the ram may be shortened or lengthened by varying the position of the adjustable crank pin from the center of the crank plate.

The Feed Motion.—A grooved cam is cut on the enlarged portion of the driving spur-wheel shaft, and by connections from the cam roller to a slotted lever on the side of the machine, the latter is given an oscillating motion, which is transmitted by rods and bevel gear to the table, where by suitable gearing this motion is transmitted to the feed screws of either the slider, saddle or to the rotating table, thus furnishing the three feeds desired.

Slotting Tools.—From the altered conditions under which these tools are used, for instance, the direction of the thrust coming parallel or nearly parallel to the shank, instead of at right angles to it, and very often, from the limited space in which they have to work, some modification of the forms employed for planing and shaping are found necessary. The principal forms

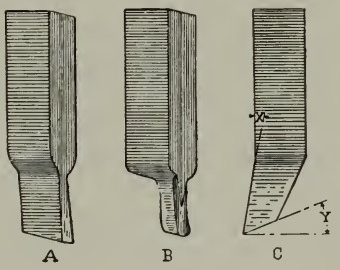


Fig. 292.

used are shown in Fig. 292, of which *A* is a *parting tool; B* is called a round edge, diamond point or *key-way* tool, according to the shape of the cutting edge. From the manner in which the tool takes the cut it is seen that the cutting angles are the reverse of those of lathe and planer tools. In the tool shown at *C*, the angle of clearness is at *x* and the angle of rake *y*, and as before the angle of clearness should be made small.

CHAPTER XII.

BORING AND TURNING MILLS AND MILLING MACHINES.

Boring and Turning Mills.—Like the principal machine tools, boring machines have been designed in various shapes to facilitate the setting and machining in special types of work. Boring machines may be either horizontal or vertical, and the representatives of these types selected for illustration are those in the Engineering Building. Ordinary screw-cutting lathes may also be utilized for boring and are analogous to the horizontal boring machine, with the exception that in the lathe the work moves, while in the regular horizontal mill either the cutter or the work may move. In the use of the lathe for boring, the rests are removed and the work set

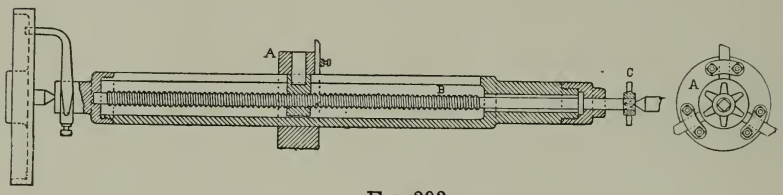


FIG. 293.

on the carriage. Between the centers of the lathe is fixed a plain boring bar, with one or more transverse slots, and into which are keyed cutting tools. The work to be bored, which must have a hole through it large enough to admit the bar, is secured to the slide rest or carriage of the lathe, the movement of which along the slides of the lathe feeds the work up to the tool. For steam-cylinder boring, or where accuracy is desired, it is essential that the feed be continuous, and the cut carried through without stopping. Other equally important points are to have the boring bar sufficiently large in diameter that the cutters be rigidly supported, and at a short distance from the cutting edge.

For larger-sized cylinders it is advantageous to keep the cylinder stationary on the bed and use a form of boring bar which permits

the feed to be given to the tool, and also to reduce the large size of the boring bar necessitated, in order to give sufficient support to the tools. Such an arrangement is employed and illustrated in Fig. 293. The boring bar is in connection with the driving spindle and revolves with it. Support is given to the cutting tools by the use of a *cutter head or boring head* A, on the bar, and into which the cutters are fixed instead of into the bar itself, two or more slots being provided for their reception, together with the keys by which they are made fast. The boring head slides along the length of the bar; the only thing needed is to give it a slow and uniform feed, which is obtained by connecting it to a horizontal feed screw B contained in a recess within the boring bar. Many ingenious methods have been used for driving the screw and giving the requisite motion. As shown in the figure, a star wheel C is secured to the end of the screw and, as the bar revolves, the points of the star strike successively a lug or pin attached to the lathe bed, thus turning the screw slightly and advancing the tool. The amount of feed per turn of the boring bar is regulated by the number of points on the star.

The Horizontal Boring and Drilling Machine.—This machine, as well as the vertical boring mill, is designed on the principal of the lathe, and practically both are modified forms of lathes, made with special adaptation for boring and facing purposes. In Fig. 294 is shown one type of this machine, which is eminently adapted for general work in boring, drilling and facing, owing to the various adjustments possible.

The table can be given a movement in a vertical direction by screws and worm wheels driven by power, and on this table is a saddle which has a movement parallel to the main spindle. Gibbed to the saddle is a cross table with a horizontal movement at right angles to the spindle, both the above movements being readily obtained by means of the adjusting screws on the side and end. By means of these right-angled adjustments any part of the work can be moved into position to be worked upon by the boring bar and cutters, thus many operations in the fitting up of moderate-sized engine cylinders, such as boring the cylinder and valve chest, facing flanges, framing, lugs, etc., may be performed without unclamping the work.

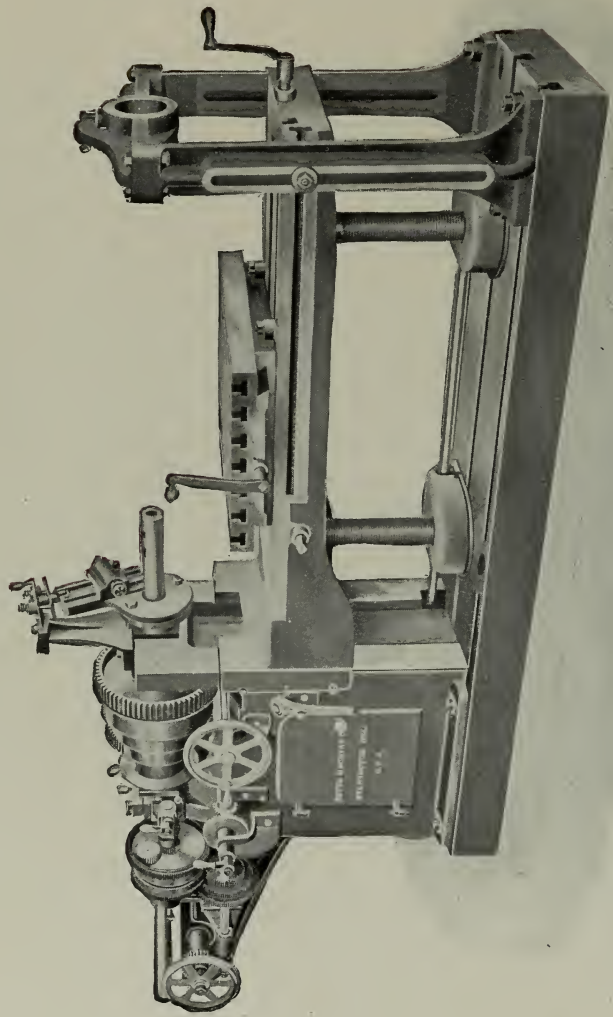


FIG. 294.

The outer end of the boring bar is supported by a bearing on the framing, movable along the base so that a rigid support may be given where heavy cutting is to be done on short work. In boring-engine cylinders, the boring bar is fitted as usual with a boring head and cutters, while the boring bar extends through to the outer bearing.

Motion is transmitted by means of a belt and the cone pulley with double back gearing. The spindle can be run in either direction, and has a long bearing through a cast iron sleeve. The feed is automatic with a wide range, as well as by hand, while this feed can be given to the spindle in either direction without reversing its motion.

The facing head is shown attached to the spindle, and can be arranged to clamp on a boring bar or to fit the hole in a steady rest yoke.

Vertical Boring and Turning Mills.—These machines are practically upright lathes, but made especially powerful and compact in order to give solidity to the table and tool and maintain a uniform and positive drive. They are used principally in turning and boring cylinders, pulleys, wheels, etc., and possess the advantage of enabling coarse feeds to be taken at high speeds. Referring to Fig. 295, the bed, housings, back and top brace are heavy and solid, making a characteristic, rigid, substantial frame for the class of work employed on this machine. The table is driven by bevel gearing and is supported by a large spindle running in a bearing bored out of the solid bed, with appropriate bushing for taking up wear. The cross rail is of the box-girder form, with accurately scraped surfaces, to which the saddles are square gibbed.

The tool bars shown are massive steel forgings housed in two adjustable bearings fitted to the swing plates the bars having a rack cut in the side through which is obtained the vertical feed, while the swing plate can be adjusted to any angle. The counter weight used acts in line with the tool bars at all angles, as can be seen in the illustration, and does not tend to pull the swings over, nor prevent the easy movement of the saddle along the rail.

The transverse slide is fed by a horizontal screw, the gearing at the end of the rail being so arranged that all the feeds are independently reversible by sliding the slip gears. In general, the arrange-

ment of the feeds is similar to that of the planing machine previously described, the driving power being obtained through a large high-speed friction plate seen near the base of the machine. This disc is in contact with a leather-faced wheel, which actuates the gear at the end of the rail, through a vertical shaft. The frictional feed motion may be instantly released, reversed, or adjusted

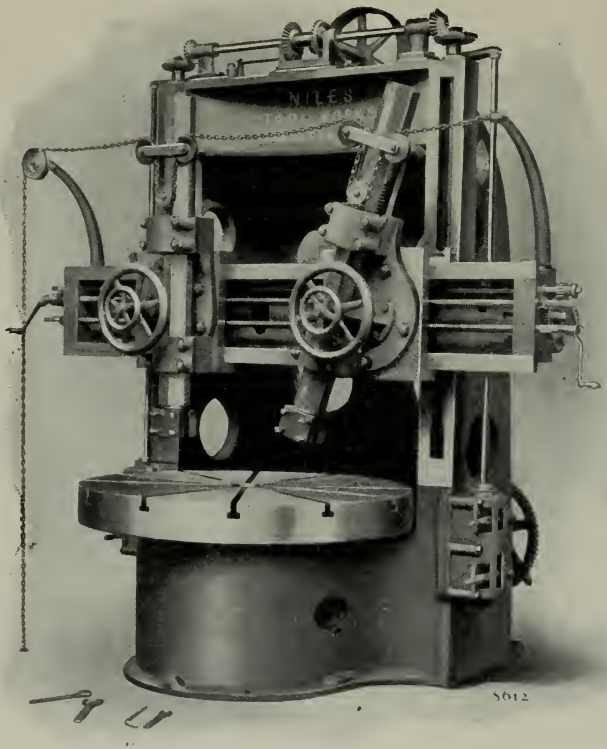


FIG. 295.

throughout its range. The driving cone and back gear are located at the back of the mill and consequently not shown in the print.

Grinding Machinery.—The old method of grinding by means of sand-stone wheels is being gradually abandoned in machine shops, in favor of wheels made of emery, corundum or carborundum. The degree of excellence to which the various machines designed

for these wheels has been brought, has made possible the close approach to perfection in the journals and sliding parts in the high-speed engine of the present day. The grinding machine has also made feasible the use of hardened spindles, bearings and other accurately fitted parts of the various machine tools, lathes, milling machines, drilling machines, etc., while in the finished work about the modern engine, both marine and stationary, the cost of production has been greatly decreased and the quality and appearance of these parts increased. To bring out all the advantages of grinding machines, however, and the production of good work, a variety of shapes, sizes, and grades of wheels are just as necessary as the variety of shapes and sizes in the cutting tools found necessary in the milling machine, lathes, and other machine tools in general use.

The material used for grinding wheels is first crushed by machinery, then the finely divided particles are mixed with a glutinous composition called the *texture*, and which may consist of hard rubber, shellac, ordinary glue, or a mixture of linseed oil and litharge, and compressed into the various shaped wheels desired. Wheels are graded by numbers, according to the size of the grain; the numbers indicating the number of meshes per inch of the screen through which the grains pass. They are also graded as hard and soft in regard to the composition of the texture.

Coarse grain hard wheels are suitable for rough grinding in which accuracy and finish are not required.

Medium grain hard wheels are serviceable in grinding lathe tools.

Medium grain soft wheels are suitable for free cutting on broad surfaces of iron, steel, or brass.

Fine grain soft wheels are used in grinding fine tools, such as milling cutters, in which the duty is light but accuracy is imperative.

Fine grain hard wheels are suitable for smooth grinding on soft metals, such as brass and copper.

It is important that emery wheels be kept clean and free from oil, and they should not present more than from $\frac{1}{16}$ to $\frac{1}{8}$ of an inch of surface to the work.

Grinding operations in general may be divided into four classes of work: *Hand grinding, tool and cutter grinding, rod or shaft grinding,* and *surface grinding.*

Hand Grinding.—Under this operation is embraced the ordinary grinding of hand and lathe tools, or any work held up to the wheel by hand, and ordinary polishing and buffing. The grinder used is

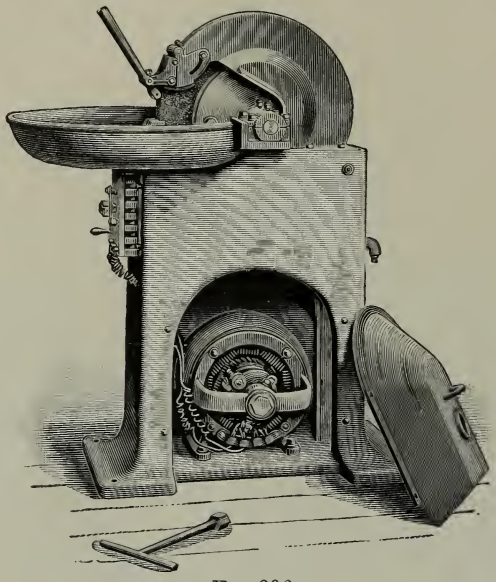


FIG. 296.

of the simplest form, Fig. 296, a grinding wheel on a spindle or shaft supported on bearings, and either belt or motor driven, an adjustable rest being provided to support and steady the tool.

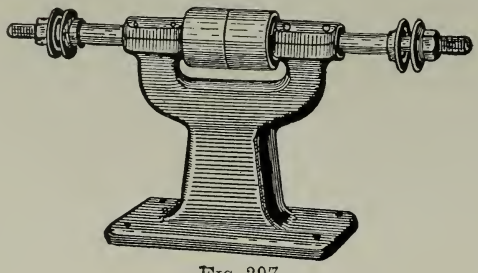


FIG. 297.

These grinders may be of two classes—a *dry grinder* or a *wet grinder*—the former being used for rough work where its becoming heated in the operation is not a matter of importance. In the wet

grinder a thin stream of water is fed over the rim of the wheel, thus keeping the tools cool in the process of grinding, and avoiding any injury to them from drawing their temper.

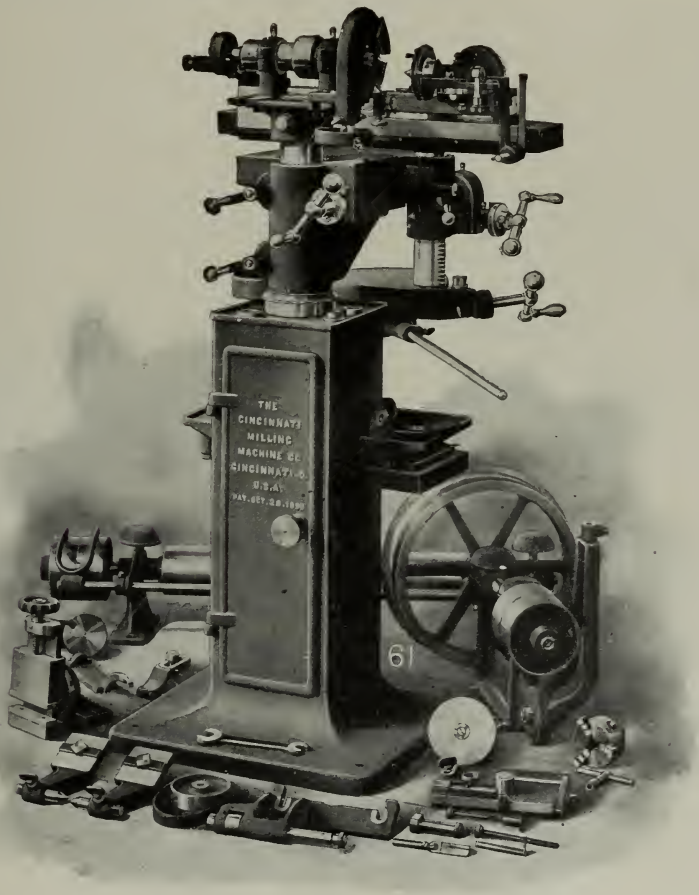


Fig. 298.

For ordinary polishing or buffing a simple machine, Fig. 297, consisting of a two-ended spindle driven at a high speed by a belt and pulley at the center, is used. On the spindles are secured wheels of wood, cloth, or leather, on which the grinding material is placed and the work held up to it by hand. Small machine parts,

articles in brass, plated goods, etc., often require polishing to a high degree; this final polish is given with *mops* or *bobs*, consisting of a number of sheets of muslin secured together by two small leather discs. These polishers or buffers are placed on a revolving spindle and crocus powder or other polishing material is used on the mops, against which the articles to be buffed are pressed by hand.

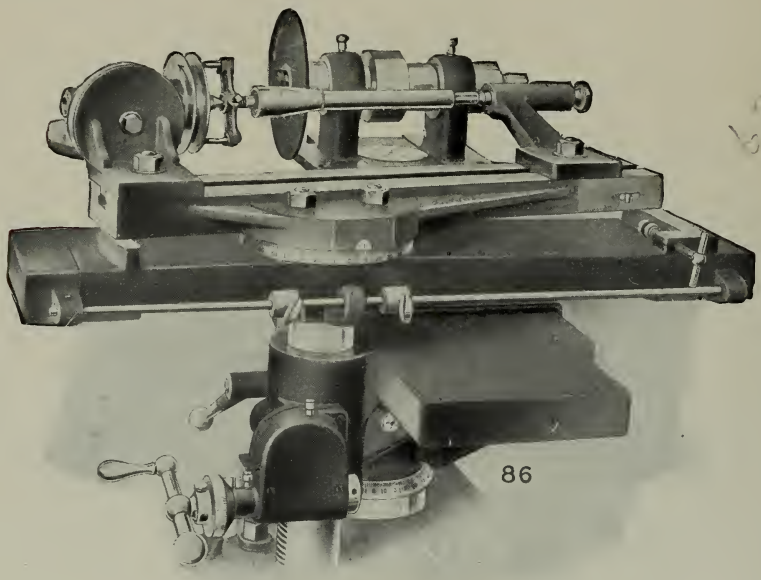


FIG. 299.

Tool and Cutter Grinding.—This embraces the operation of grinding twist drills, reamers, the various cutters used with the milling machine, and the high-grade tools used in an engineering establishment. For the regular shop tools for turning, shaping, planing, screw cutting, and other tools, the advantages of a special tool grinder are decided, for the best cutting angles, clearance, rake, etc., can be correctly set on the swivel tool holder and the tools ground uniformly and properly, a condition not always found to be the case where each workman uses his own individual taste in grinding. As mentioned before, this variation does not exist where

the grinding of tools is all done by a distinct set of men in a separate tool room, or tool-grinding room, as is practiced in many large establishments.

In Fig. 298 is shown a *universal cutter and tool grinder*, fitted with all the necessary attachments and adjustments for grinding

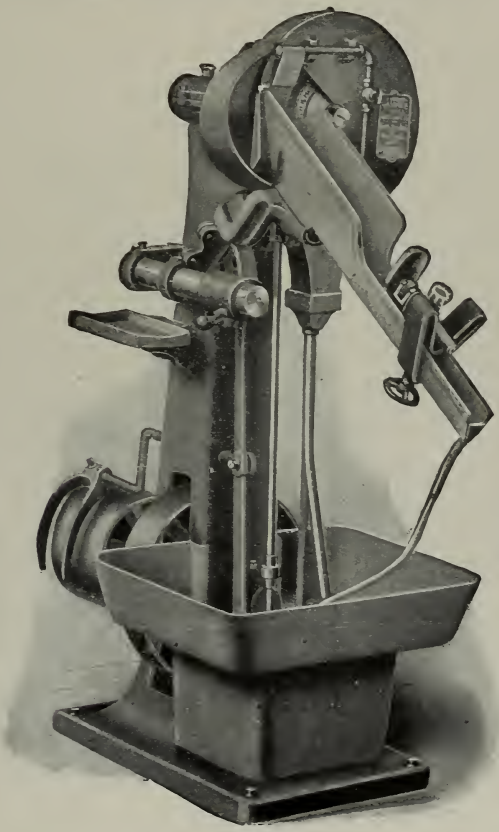


Fig. 300.

milling cutters and reamers, while it is also an efficient tool for cylindrical, internal, face, surface and angular grinding.

On account of the complete universality obtained by the independent movements of the knee, table, and swiveling head, a large amount of work can be ground by using cup-shaped wheels, thus giving a straight line clearance to the cutting edges of the teeth.

The kinds of work which can be ground on this machine are so numerous, that but one example is shown in Fig. 299, the grinding of a taper spindle. In this example the work is revolved between dead centers and the table adjusted vertically to bring the work center to the same height as the center of the emery-wheel spindle. The table is then set to the required angle, read direct in inches

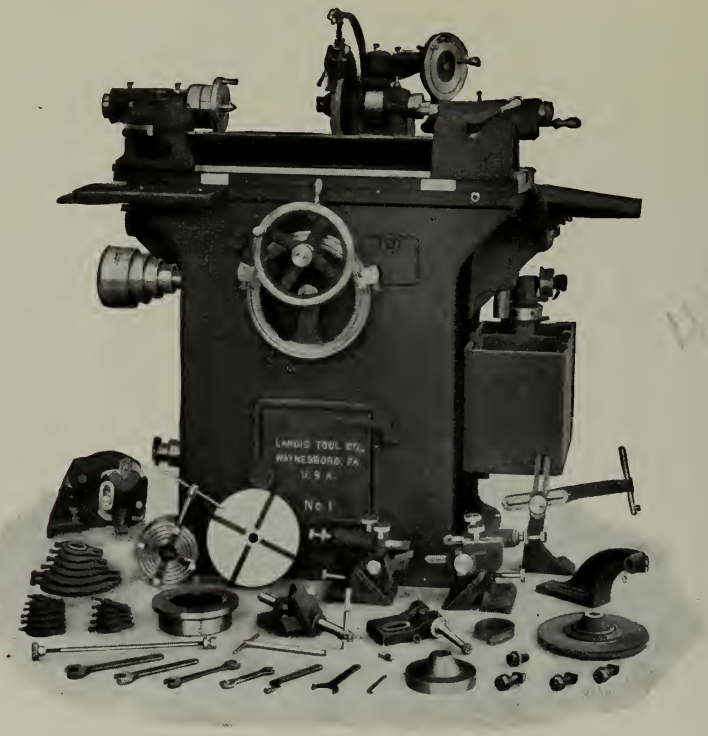


FIG. 301.

per foot from the scale at the end of long slide, or in degrees from the index on the swivel base. The illustration shows the arrangement of the stops for limiting travel of the table.

The Twist Drill Grinder.—The grinder, shown in Fig. 300, shows a ready means of grinding twist drills without any adjustments. The drill is simply placed in the V-shaped holder and the tail

stock brought up until the drill is in contact with the grinding wheel. Generally, in drill grinders, a certain number of adjustments have been found necessary to suit the different size drills in order to obtain the proper clearance from center to periphery, but in this case the size of the drill itself determines the proper position in the holder. For instance, a $\frac{1}{2}$ inch drill always stops at a certain place and can not possibly occupy the position intended for a $\frac{3}{4}$ inch drill, with the result that all drills are properly ground and at the correct angle.

Cylindrical Grinding.—Under this head is placed the grinding operations upon cylindrical surfaces, both externally and internally. In Fig. 301 is represented the typical form of lathe or machine used for this work, and consists essentially of a table with shears, a suitable head and tail stock and an adjustable platen with a wheel stand fitted with a swivel head. The platen on which the head slides can be set either parallel to or at an angle with the line of work centers, thus enabling long tapers to be ground, while the adjustments capable with the swivel head carrying the grinding wheel, make possible face and steep angle grinding. As the work is driven by its own pulleys, while the grinder has its independent belting and pulleys, the counter-shaft differs from the ordinary arrangement to permit this action; the driving pulley for the grinder being made with a very long face to permit the belt to travel upon it as the head and grinding wheel are fed along the table.

Machines of this character are intended to produce very true work, consequently they are well designed and accurately constructed, and their efficiency largely depends on the care and attention given to them.

Surface Grinding.—In Fig. 302 is illustrated the general form of surface grinders, and consists of a framing, on the top of which is the movable table, to which the work is secured, and is fed horizontally under the grinding wheel. The depth of the cut is regulated by a vertical adjustment of the wheel, while cross slides enable a horizontal feed to be given to the table and work.

In the use of grinding machines and grinders, care should be taken in setting and in the condition of the machines, inaccuracies and poor work results from poor fitting centers. All centers should

be of the standard 60° angle, and with sufficient surface to give a good bearing. The center should fit the work and be kept clean and well oiled. In any work where a change of temperature, due to grinding, may injuriously affect it, water should be used, while in very accurate work water should always be used, as even a slight change in temperature may impair its integrity.

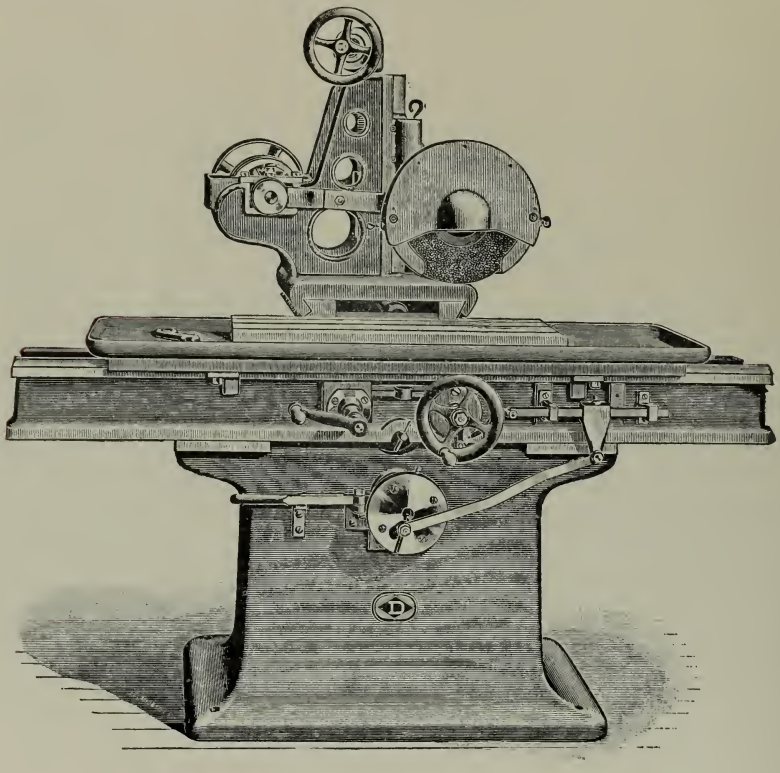


FIG. 302.

Owing to the great centrifugal force developed in the wheel, the manner of holding it is of importance; it also should be symmetrical, as any undue or irregular pressure brought upon it by the fastenings may crack it. In mounting wheels, washers of rubber, felt, or paper are usually placed between the securing flanges and the wheel.

The wheel is usually run at a speed as high as practicable, without injury, and varies according to the grade of the wheel, character, and size of the work.

Truing Emery Wheels.—In order to obtain a good cutting edge and make a smooth finish on work, the emery wheel must run true and have its cutting surface parallel with the movements on the slide of the machine. On work ground between the centers it is essential that the wheel be perfectly true. In order to accomplish this, the wheels are trued up by means of a *diamond tool,* which may be used either by hand or in a tool rest, so that the diamond can be passed across the wheel in line with the slide in any position.

Lapping.—This method is used for the final finishing of machine-ground surfaces and consists of a body usually of cast

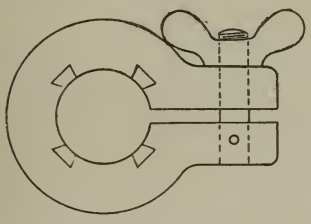


Fig. 303.

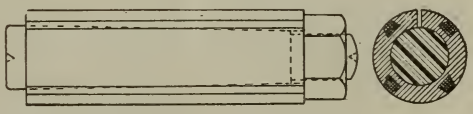


Fig. 304.

iron, into which are dovetailed strips of copper or lead. On coating the surface with very fine emery or other grinding material, it is worked over the surface as uniformly as possible. For cylindrical surfaces the lapping tool is commonly made as shown in Fig. 303, the casting shown being of iron with strips of lead or copper inserted along its inner surface. The tool is placed on the shaft and coated with emery and oil, and the shaft run at high speed. The tool is moved slowly from end to end of the shaft, thus obtaining parallel work. The work is reduced to the required size as grinding proceeds, by setting up on the clamp or thumb screw shown on one side.

In finishing bores a similar method is employed as shown in Fig. 304, and consisting of a plug in length to suit the size of the work. Strips of copper or lead are fitted along the length, and the plug made capable of being slightly expanded by a wedge or screw, as needed during the grinding to size.

For flat surfaces the lapping is performed by a cast iron plate, similar to a surface plate, but with plugs of lead or copper inserted in its face and then planed true. The surface being coated with emery and oil is rubbed over all parts of the work equally, and with a constantly changing direction of motion in order to grind uniformly over the surface.

Milling Machines.—Milling is the operation of cutting metal by revolving cutter wheels, and has a remarkable adaptability to the machining of surfaces on a great variety of work, far exceeding that accomplished by the shaper and planing machine. Since, in the planer and shaper, the profile of the work is done by changing the position of the cutting tool, measurements and adjustments are necessary from time to time. With the milling machine the profile is cut as the cutter advances, the cutter or combination of cutters being of a form to develop the profile, necessitating only initial measurements in the first setting. The milling machine also possesses a great advantage over the shaper and planer when quantities of duplicate parts are to be manufactured, both regarding the accuracy in the work and economy in the production.

Horizontal spindle milling machines are of two kinds, *plain* and *universal;* the distinguishing feature of the latter is in the design, which permits swiveling the table so as to bring its axis at any angle with the spindle, and can be used for automatically milling spiral forms. The plain miller is without the swiveling feature, the table being held rigidly at right angles to the spindle.

The *universal type* is represented in Fig. 305. As in the shaper, it has an upright base, called the *column,* and a *knee.* A heavy steel *overhanging arm* acts as a support for the outer end of the *spindle* and is located above the spindle and rides in a long sleeve. The overhanging arm may be reversed or removed altogether to take in any attachments.

The table is gibbed to the knee and is capable of adjustment away from, or towards, the face of the column, while the knee itself is also gibbed to the face of the column and can be given vertical adjustments. The table is slotted for clamping the work, and by means of a swivel base, can be set at any angle from its normal right-angle position with the cutter spindle, for cutting spirals, or, if the work requires it may be swiveled 360 degrees.

The feed mechanism is complete and designed for a wide range, the *slider* being gibbed to the knee enables a longitudinal feed parallel to the spindle to be given, the table itself works in gibs on the

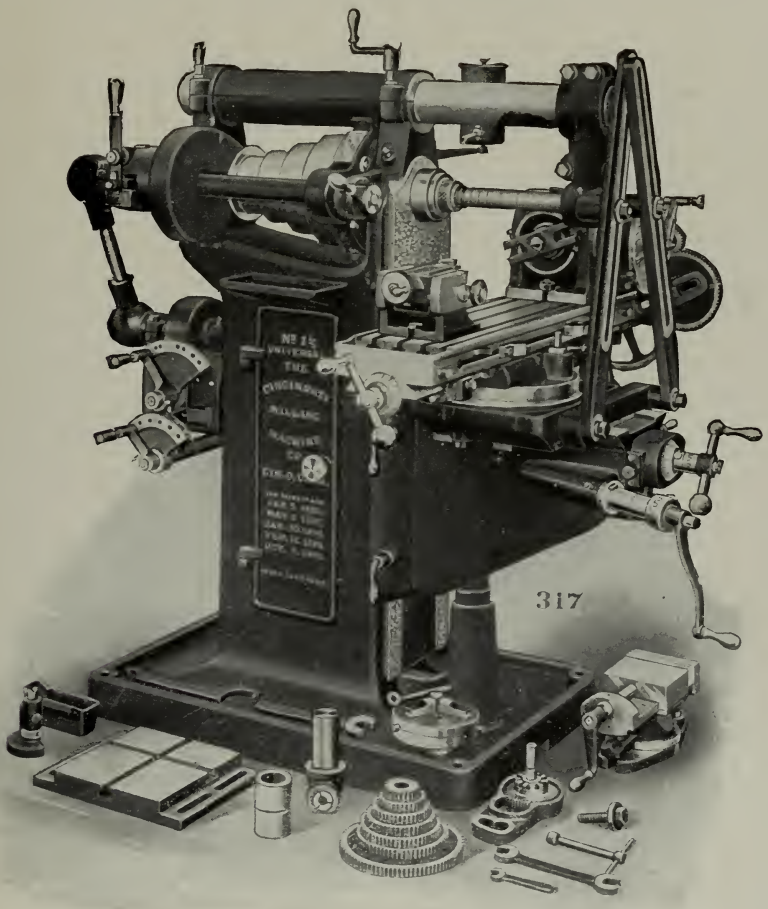


Fig. 305.

slider, thus giving a cross feed, while a vertical feed is also provided. These feeds are automatic and can be readily operated by simple movements of levers in front of the knee.

The spindle is of steel, hollow, and at the front end the hole is

made to the standard taper gage to receive the cutter arbor. The spindle is driven in the usual manner by a cone pulley in the upper housings, as shown in the illustration. Cutters are placed on a *cutter arbor* and secured in place by sleeves and a securing nut, and the taper end inserted in the tapered spindle, and the other end supported by the overhanging arm, by means of an adjustable center or bushings.

The *plain milling machine* is similar in construction and appearance to the universal machine, the table is gibbed directly to the slider and has travel at right angles to, and parallel to, the spindle only. The machine is more rigid in construction and simpler in its parts than the universal.

The vertical milling machine is designed for work when the operations can be better performed by a cutter working on a vertical spindle instead of one by the horizontal spindle type. The column in this machine is carried up, and then brought out over the table in order to bring the spindle in a vertical position.

The attachments for milling machines for the varied style of work performed are numerous, and among the principal ones may be mentioned the divided head; the spiral head for spiral milling; index centers; under cutting gear for cutting spur gear of large diameter; spindle milling attachments for performing vertical milling on a horizontal spindle universal machine, and used for key seating, die sinking, cutting tee slots, etc.; rack milling attachment to revolve the cutter at right angles to the spindle, permitting racks of any length to be cut; slotting attachments, cam milling attachments, and rotary milling gear for milling circles or segment of circles.

With the machines described in the preceding pages, the belt drive has alone been considered, the power being given to a main shaft by belting from an engine or motor, thence to the countershaft, and finally to the cone pulley of the machine. These tools are frequently employed with individual electric drives, thus dispensing with the overhead wilderness of belts, shafts and pulleys. Numerous examples of this system can be seen in the different shops of the Engineering Building, together with the group system of electric driving.

CHAPTER XIII.

THE BOILER SHOP.

Boilers are built up by riveting together plates rolled to the desired form, together with other fastenings and connections through the agency of various section bars, such as angle, tee, flat, square and round bars. For water-tube boilers these materials are further augmented by tubes, piping, and fittings, which constitute in this class the larger part of the boiler structure.

Boiler plates, rivets, and tubes are of steel, and for naval vessels, in accordance with Department specifications.

The ordinary outfit in the shape of machine tools for the boiler shop of an engineering plant consists usually of the following:

1. Punching and shearing machines.
2. Plate edge planing machine.
3. Plate bending rolls.
4. Metal sawing machine.
5. Hydraulic flanging machines.
6. Hydraulic riveting machines.
7. Portable hydraulic riveters.
8. Pneumatic riveting machines.
9. Pneumatic calking machines.
10. Pneumatic beading tools.
11. Pneumatic tube-expanding tools.
12. Drilling machines.
13. Gang and multiple drills.

Tube cutters, ferrule extractors, boilermaker's hearth, annealing and re-heating furnaces, rivet heating forges, and the various lifts, tackles, cranes, etc., operated by compressed air, steam, electricity, or hydraulic pressure.

As the materials used are principally large plates cumbersome to handle, the boiler shop should be laid out so that the work is done in a progressive manner, the tools so arranged that the work passes from one to the other in the order of the operations to be

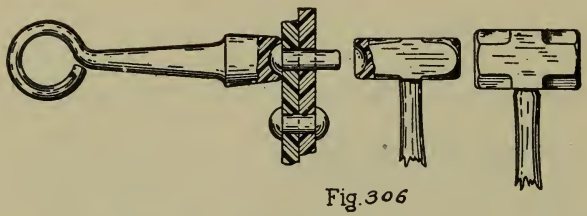


Fig. 306

Fig. 307

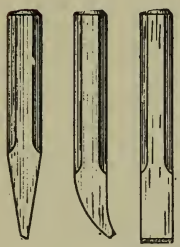


Fig. 308

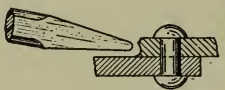


Fig. 309

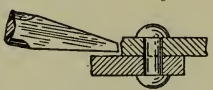


Fig. 310

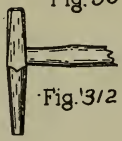


Fig. 312

Fig. 311

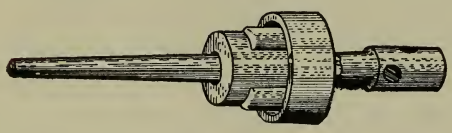


Fig. 313

Fig. 314

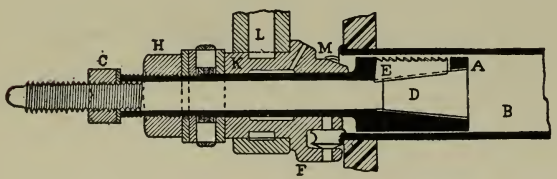


Fig. 315

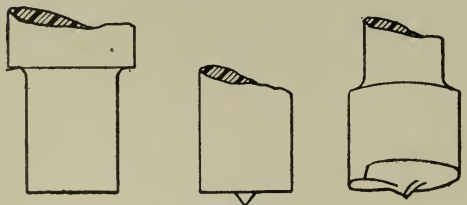


Fig. 316

performed. To do this with the least handling, the heavy machine tools for use in the different operations should be arranged in the order they are required, with ample space and an efficient system of cranes for passing the plates as they go through the various stages of shearing, punching or drilling, planing, rolling, and riveting. As the shell work is completed the boiler is brought to the erecting floor, where the furnaces and combustion chambers are put in place and the tubes fitted. In addition to the various auxiliary cranes feeding the different machines, a traveling crane should pass through the shop, and capable of picking up the largest boiler produced.

Of the principal hand tools required by the boilermaker may be mentioned the following: For marking off; wing compasses, dividers, compasses, scriber, surface gage, center and prick punches.

Many of the remaining hand tools are similar to those used at the forge, page 137, such as fitters', sledge and riveting hammers, chisels, both curved and flat, swages, curved face flatters, punches, calipers, gages, angle-nose tongs, round-nose tongs, and rivet tongs. In addition to the above, the boilermaker requires drifts, calking tools, clamps for securing plates temporarily, beading tools, tube expanders, rivet holders, and cupping tools or snaps. These tools are illustrated in Figs. 306 to 316. If the parts to be riveted have been drilled separately, they are brought together with their corresponding rivet holes in alignment and bolted in a few places, the *drift,* Fig. 307, is then used to clear out the holes. The use of this tool to force holes in alignment and distressing the metal in the vicinity of the holes is absolutely prohibited in naval and all high-grade work. The handle chisel is employed to break off the head of a rivet, and the *punch,* Fig. 312, to drive the rivet out when the joint of a riveted plate is to be broken.

Calking tools are used for bringing the extreme edges of one boiler plate close to the other plate after riveting, in order to prevent any leakage.

The tool is held at an angle of about 20 degrees and driven by hammer blows, thereby upsetting the edge against the sheet, the tool being moved along the edge of the sheet during the operation. To prevent cutting the surface of a plate, the edge of the tool is more generally made convex or rounded, as shown in Fig. 309. For butt

joints the tool and method is as in Fig. 311. Punches are made of the forms shown in Fig. 316, cylindrical with a flat end, with a center for feeling for the puncture in the sheet, or with a helical end to lessen the distress inflicted upon the metal. For work upon the boiler the holes must be drilled, as the plates are not injured in the operation and the holes are more readily and correctly spaced. There is no difficulty in drilling after bending, as the plates are secured by temporary bolts and the rivet holes drilled in position, thus insuring accuracy. The plates must be taken apart after drilling and the burr or sharp edge of the drilled hole removed.

Tube Expanders.—Boiler tubes may be seamless, or lap-welded iron or steel tubes. For the U. S. Navy, the specifications require cold drawn seamless steel tubes. The tube ends after being placed are expanded tightly in the tube-plate holes, and beaded over at the fire end; consequently, they must be ductile enough to withstand the treatment. The tool used for this operation is shown in Fig. 313, and consists of a cylindrical frame with three steel rollers working in slots, the rollers being pressed out by a taper pin passing through the center of the frame. When the tube is placed in position, the frame is pushed in the end of the tube and the rollers set out by the taper pin, and expands the metal of the tube against the sides of the hole in the tube sheet. This operation is repeated, the pin being turned each time, thus revolving the rollers until the whole circumference has been expanded or set out.

Tube Beader.—Boiler-tube ends are *beaded* by means of the *boot tool* shown in Fig. 314. The work can also be done by tube-beading machines, possessing the advantages over the hand tool of greater rapidity and smoothness. One type of a machine-tube beader is illustrated in Fig. 315, and is operated as follows: The fixing piece A is secured in the boiler tube B by the action of the nut C, which draws the coned mandrel D outward and forces the three wedge pieces E against the tube walls. The body F of the beader is then brought into position, so that the three beading rollers bear upon the tube end at M. A gradually increasing pressure is brought to bear upon the rollers by the nut H, while the body piece, carrying with it the beading rollers, is made to revolve upon the fixing piece A by means of the ratchet wheel K and pawl L, thus rapidly forming the bead M upon the end of the tube.

Cold Drawn Seamless Steel Tubes.—The specifications for boiler tubes for U. S. Naval vessels call for *cold drawn seamless steel tubes.* Their manufacture, as briefly given below, is greatly abridged from a paper by Lieut. Newton Mansfield, U. S. N.*

The material is mild, open-hearth basic steel, and received at the tube mill in round bars three to four inches in diameter and from eight to ten feet long. These bars are heated to a cherry red in a gas furnace and sawed to a length commensurate with the length of the finished tube. These lengths or billets are re-heated

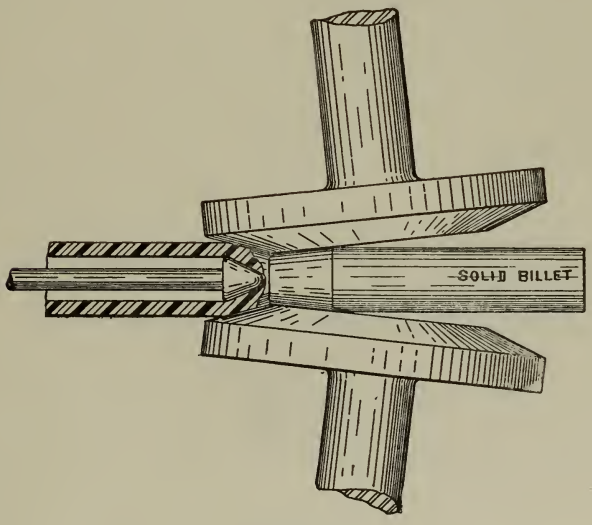


Fig. 317.

to a light yellow and then delivered to a piercing mill, the principal of which is shown in Fig. 317.

The mill consists of two cast steel discs on the ends of two shafts whose center lines lie in the same plane but slightly inclined to each other. The shafts revolve in opposite directions and the faces of the discs can be made to approach to, or recede from, each other by adjusting screws, thus accommodating billets of different diameters.

* Journal American Society of Naval Engineers, Volume XV.

The billet at a yellow heat is laid on a guide so that the axis of the billet is in the same plane with the axis of the disc, and then fed in by hand until the end takes against the revolving discs. The principal of a belt climbing to the high side of a pulley, forces the billet on to the hard steel piercing point, which pierces the billet, while the beveled surfaces of the disc roll the pierced billet out smoothly as it advances over the piercing point. The piercing point and its mandrel are firmly supported, so that the point enters the center of the billet, but is not held rigidly in place, but allowed to revolve with the billet. Its rear end is held in a swivel strong enough to take the thrust of the advancing billet. Both discs are constantly cooled by a stream of cold water.

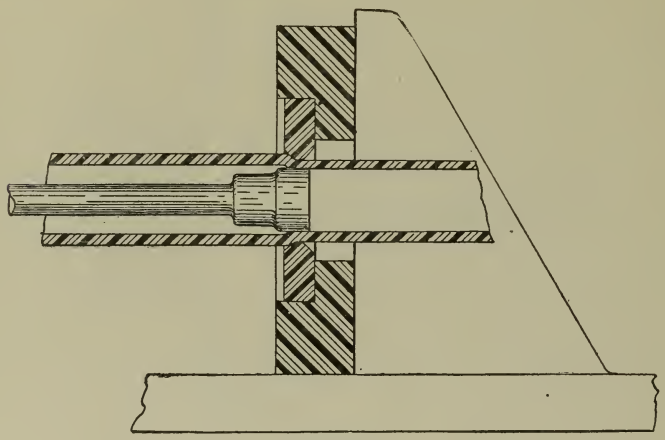


FIG. 318.

If the temperature is correct the billet goes through the mill and comes out with a smooth, central, longitudinal hole, and about twice its original length. Without cooling it is passed immediately through the rolls, similar to steel mill rolls, but as the tube is rolled it is made to slide over a mandrel whose point is held between the rolls. The tube is given from four to eight *passes* through the rolls, turning the tube through 90 degrees after each pass in order to produce walls of uniform thickness. The tube is now from four to five times the length of the original billet, and the walls are one-fourth inch in excess of the required finished thickness.

The tube is now cooled to the temperature of the air, and about six inches of the end beaten down to a point, so that the end may be started through a die of smaller diameter than the tube. The tube is then taken to the pickling room and the scale removed in the pickling bath, after which it is washed. The tube is now immersed in a mixture of tallow and flour paste, the operation being called *dopeing*. After dopeing, the tube is dried in an oven and is then ready for the cold draw bench. The principal of the operation is shown in Fig. 318. The pointed end of the tube is closed, while the other end is open, and into the latter the mandrel is shoved until it takes against the pointed end. The mandrel is carried on the end of a long rod, the other end being secured to the draw bench to hold the mandrel in its proper position relative to the die.

The pointed end of the tube, with the mandrel on the inside, is passed into the die and drawing pliers grip the point. Toes on the pliers engage an endless sprocket chain which, as it travels slowly, draws the tube through the die. After the passage the tube is reduced in diameter and thickness, and lengthened about 20 percent of its original length. Both outside and inside surfaces are smooth. After a tube has made one pass, it is annealed, pickled, doped, and dried before making a second pass.

The number of passes required varies with the size and thickness, the 2-inch, 8 B. W. G. tubes require two passes in which the diameter is reduced from $2\frac{1}{2}$ to $2\frac{3}{16}$ inches, and from $2\frac{3}{16}$ to 2 inches, while the thickness is reduced from $\frac{5}{16}$ to $\frac{7}{32}$ to 8 B. W. G.

For tubes of 1-inch diameter and 11 B. W. G., at least five passes are taken. The reductions of diameter are from $1\frac{1}{2}$ to $1\frac{3}{8}$, $1\frac{1}{4}$, $1\frac{3}{16}$, $1\frac{1}{8}$, and 1 inch respectively, while the thickness is reduced from $\frac{1}{4}$ to $\frac{7}{32}$, $\frac{3}{16}$, $\frac{11}{64}$, $\frac{5}{32}$ and 11 B. W. G.

After the above operations, annealing, cutting to length, and inspection follow.

Machine Tools.—Riveting machines and presses are usually operated by hydraulic pressure, while the other machine tools, including portable riveting machines, are driven by belting from a line shaft with pulleys, by compressed air, or by attached steam engines or electric motors.

Plate-Bending Rolls.—These machines are built in a variety of designs and dimensions. The rollers may be arranged either in pyramid form, or the two pinching rolls may be placed one over the other and the bending roll placed at the back. In this latter arrangement the upper and lower pinching rolls are geared together, while in the pyramid type the lower rolls are geared together, both revolving in the same direction and at the same speed. The top or bending roll may run idly, the plate being fed through by the movement of the lower ones or, in the case of very heavy plates, the bending roll may also be power driven. The pinching rolls revolve in fixed bearings, while those of the bending roll may be raised or depressed by screw gearing by hand, or, what is more usual, by power, either belt gearing, or through independent motors, and independent of the main driving power.

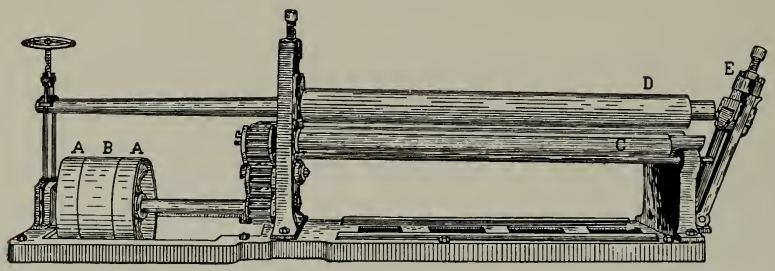


FIG. 319.

The common form of bending roll is illustrated in Fig. 319. The lower rolls are connected by powerful gearing to the driving shaft, which is operated by crossed and open belts to obtain reversal, the outer pulleys, *A-A*, being loose while the inner one is fixed. The belts are fitted with a fork connected, to a lever by means of which either belt may be thrown on the fixed pulley and its direction of motion transmitted to the rolls.

The plate to be operated upon is placed upon the lower rolls, one edge introduced, and the upper roll lowered until it grips the plate; the machine is then started and the plate is run through nearly to the other edge, then the top roll is screwed down, the machine reversed, and the plates brought back. This is repeated until the bending roll has been lowered sufficient to give the desired curvature to the plate, when it is released at the front of the rolls.

When a plate is bent into a complete circle, as in the case of a ring or flue, it can not be removed from the front, so one bearing of the upper roll *E* has a hinge, and may be thrown back, leaving the roll free for its removal.

The bending effect of the roll does not extend completely to the edges of the plate, as shown in Fig. 320, as in this position the top roll does not exercise any bending effort. The length of this straight part may be reduced by making the lower rolls smaller and bringing them closer together. In practice this straight part is bent by placing a narrow beam of wood or a bar of curved iron, Fig. 321, on the straight part, and thus bringing a local pressure to bend this part.

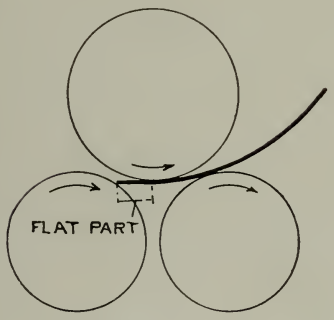


FIG. 320.

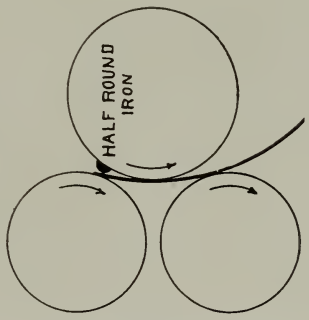


FIG. 321.

Vertical bending rolls are useful for bending long plates to large radii. The floor, which may be covered with sheet iron, affords a good support and guide for large cylindrical work, and thus avoid the trouble encountered with horizontal machines, in the constant manipulation of overhead cranes to support the large heavy sheets going through the rolls. The vertical rolls also have the advantage of giving a truer finish to the ends of the bent plate.

Plate straightening rolls are similar to the bending rolls in construction, and consists of four top and three lower rolls. The upper rolls can be raised or lowered together and each provided with graduated scale for adjustment. The lower rolls are fixed in position and driven by gearing, by belting, or independent motor. The plates are repeatedly passed through until they are truly plane.

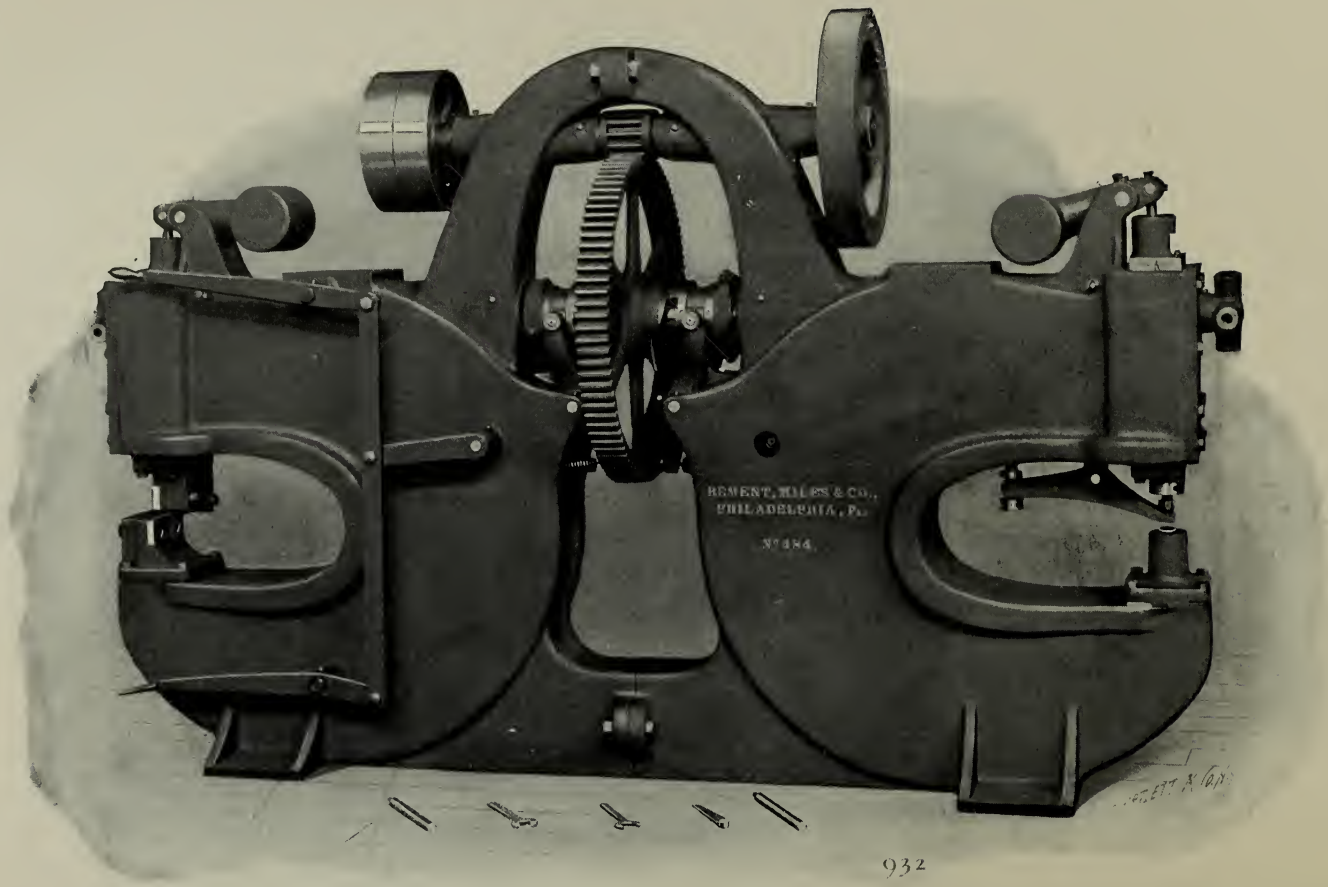


Fig. 322.

Punching and Shearing Machines.—After the plate is marked off it is taken to the shearing machine for the removal of the superfluous metal in shaping it to form. Shearing and punching machines are made separately, or they may be made combined, one end for punching and the other for shearing, and may be driven by belting or direct-connected steam engines or electric motors.

In Fig. 322 is illustrated the common form of combined machine, belt driven. For the shearing end the lower knife is secured in place while the upper knife is secured to a vertical slide, driven by an eccentric on the inside of the slide head, and at the end of the horizontal eccentric shaft. The eccentric shaft is connected to the driving shaft between the two ends of the machine by means of a clutch coupling operated by a hand lever and foot treadle shown on the side of the front head, by means of which the eccentric shaft may be coupled to, or uncoupled from, the driving shaft.

Motion is transmitted to the driving shaft by means of a belt and a fast and loose pulley, the pulley shaft having a pinion fixed to it and gearing into a large spur wheel, to give the necessary power to the knife. A fly wheel is carried on the pulley shaft to give the requisite steadiness to the machine and to carry a reserve power to prevent too great a reduction of speed while shearing. The weight of the sliding head is counterbalanced by a weight and lever shown in the illustration.

The punching machine is located at the opposite end and resembles the shearing machine, except in the tool used. The sliding head receives its motion in the same manner as the other, and the eccentric shaft is connected by a clutch with hand and foot lever connections as before. The fork shown just above the die prevents the rising of the plate as the punch is withdrawn.

Plate Planing Machine.—This machine, Fig. 323, is intended to operate on the edges of ship plates, boiler plates, etc., and consists of a table sufficiently long to accommodate the longest plates to be treated, and to which the work is clamped down by a number of trolley jacks carried in a massive beam above the saddle. The latter is traversed by a central screw driving a carriage containing the tool head, the latter being of the reversible type, that is, when the saddle has reached the adjustable stop in the front of the machine, the motion of the saddle is automatically reversed, the tool box can be turned, causing it to operate in the opposite direction.

NILES TOOL WORKS
HAMILTON OHIO
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5195

Fig. 323.

The Universal Flanging Machine.—For flanging the various parts of the boiler, for instance, the head plates, furnace flanges, etc., flanging presses are employed, usually of the form shown in Fig. 324, and originally known as Tweddell's. The framing of the machine contains two vertical cylinders with pistons or rams *A* and *B*, a die keyed to the former holding the plate, while one on the ram *B* performs the flanging. A horizontal ram *C* acts upon the flange and finishes or squares up the flanged portion. The

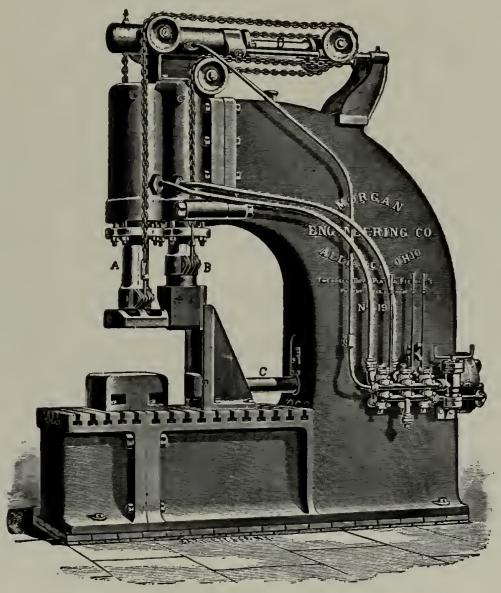

FIG. 324.

upper horizontal ram *D* raises and balances the vertical rams to which it is connected. In Fig. 326 the machine is shown in the act of flanging a boiler head plate *E*, which is firmly held down by the head block *F*, while the moulding die *G* is driven down the side and bends the plate. At the completion of each stroke, *B* is lifted by opening the exhaust of its cylinder, when there being a constant pressure supply on ram *D*, it moves out, carrying upward the ram *B*. The plate *E* is then turned and the ram and moulding die again descend. When the flanging in one heat has been completed

the side will be found crumpled and frilled, and is corrected by forcing out the ram *C* against the circumference of the flange. The plates are heated at the parts requiring flanging and from four to six feet in length can be flanged at each heating. For the extreme ends the flanging is done by hand.

Furnace holes are expeditiously flanged by this machine in one operation. The holes for flanging having been bored out to the proper diameter, the circumference is heated and brought over a cast iron ring mould secured to the bed plate. The two vertical plungers are connected together and to a strong cast iron die of the proper size, and when the furnace plate is heated and in position

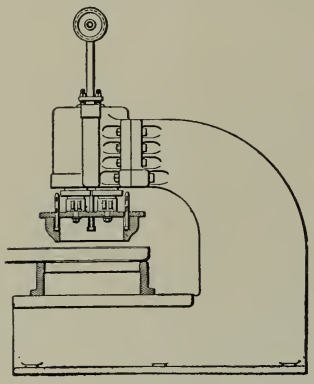

FIG. 325.

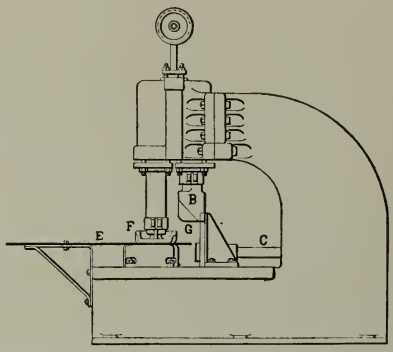

FIG. 326.

over the ring mould, the die is forced through it, producing the required flange, Fig. 325.

The valve box on the side of the machine has three levers, each working for pressure and exhaust, and by means of which any one of the rams *A*, *B* or *C* may be operated.

Riveting Machines.—Rivets are driven by a succession of blows, by the direct pressure of steam to a piston connected to the riveting head, by hydraulic pressure, or by the pneumatic riveter in which the rivet is closed by impact as well as pressure. For heavy work, such as riveting the thick plates used in boiler construction, the hydraulic riveting machine is the one most generally used, and possesses the advantages of the application of a steady and definite

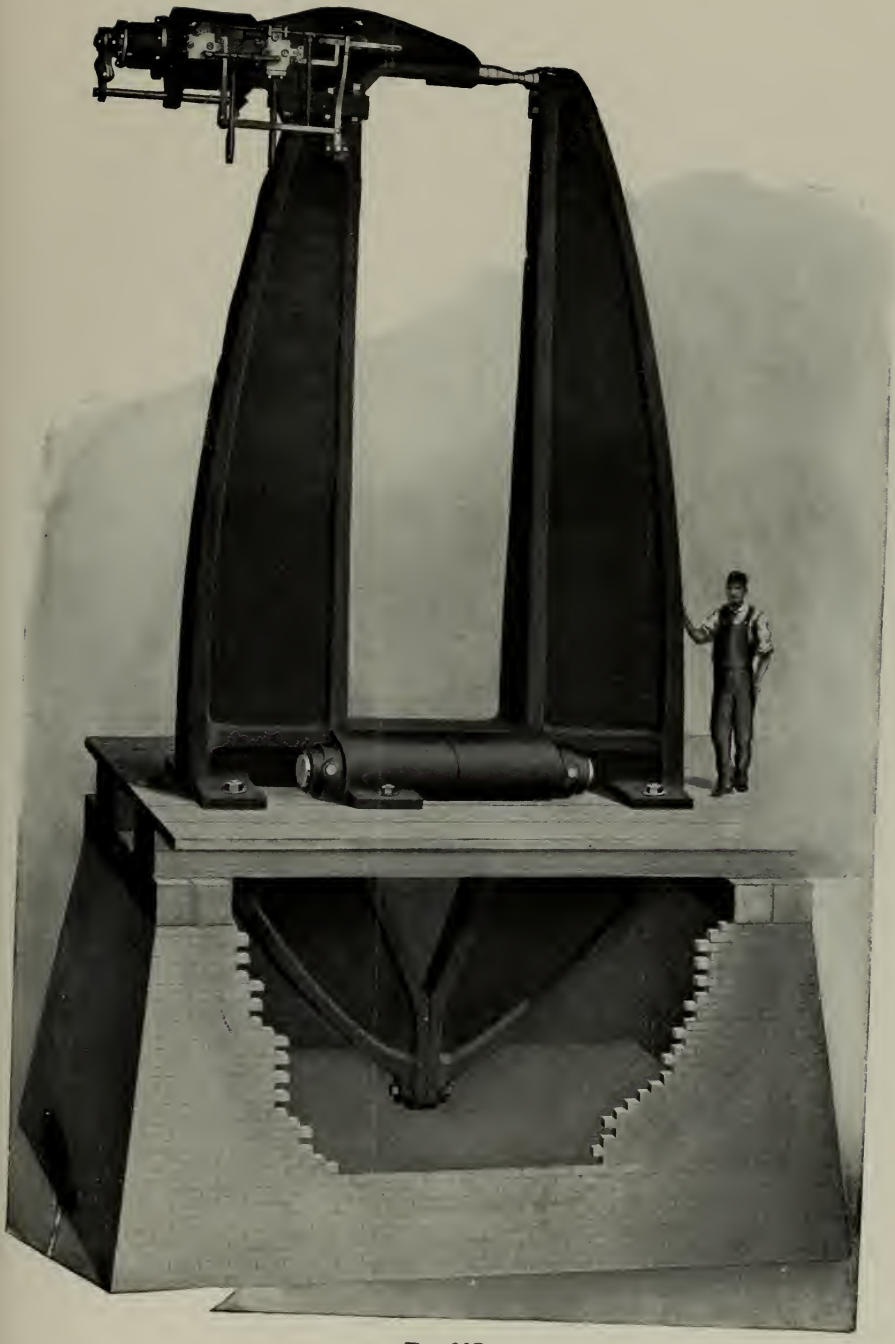

FIG. 327.

pressure to the rivet regardless of the thickness of the plates. The powerful pressure employed upsets the shank, fills the hole completely, and tightly closes the plates, while the transmission of the power is attended with ease and convenience.

Steam riveters have been practically superseded by the other systems, on account of the low pressure employed, necessitating large cylinders, the expansability of the steam, the sudden and hammer-like blow delivered tending to the crystallization of the rivet, and the wasteful use of the steam due to leakages.

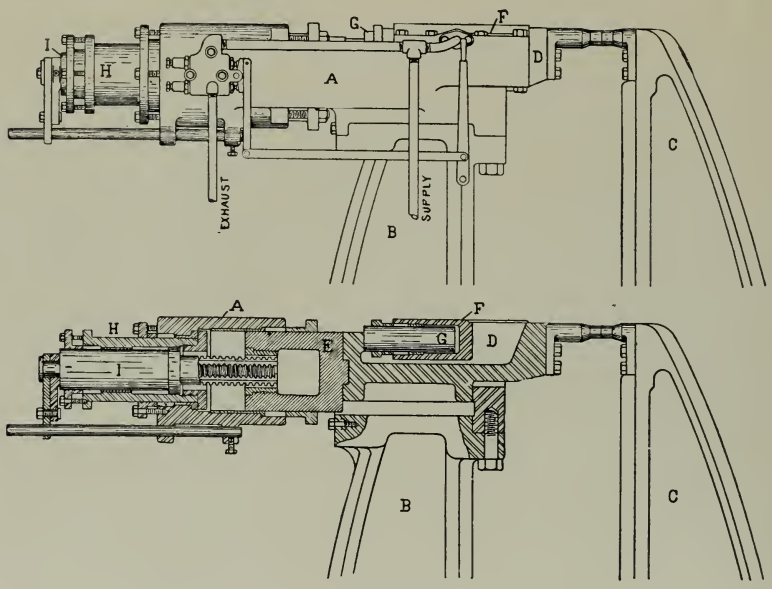

FIG. 328.

Pneumatic riveters are largely employed for hull and structural work, and while open to the same objection as in hand riveting, viz., a succession of blows crystallizing the rivet material, and also imperfectly filling the rivet hole, the extremely rapid action of the pneumatic hammer appears to overcome it in this case and excellent results are obtained from its use wherever applied.

Hydraulic riveting machines are employed for boilers and general shop work, and for the heavy plates, such as $1\frac{1}{4}$ inch, used in

marine cylindrical boilers, they become a necessity in order to secure tight joints. Hydraulic riveters may be fixed or portable, an example of a modern type of the former class being illustrated in Fig. 327. The machine consists of two heavy cast steel beams, called *stakes,* bolted together near the middle and at the lower end, and of sufficient strength to withstand the stresses produced when closing and forming the rivet. At the upper end of one beam is carried the hydraulic cylinder and ram, while the other leg carries the fixed die. The boiler seam is placed between the fixed die and the heading tool on the end of the ram, the width of the plate operated upon being governed by the *reach* or distance from the dies to the bed plate at the middle of the machine. The stroke of the ram is adjusted by the lever shown, controlling the supply and exhaust valves.

The machine shown is of the triple pressure or power type, so that by shutting off the pressures from different rams, plates of various thicknesses can be operated upon. This is accomplished, as shown in Fig. 328, as follows: The main cylinder A is mounted on the stake B and is fitted with a ram E. The small ram I is attached by means of an interrupted thread and nut to the main ram E. When so arranged E and I move together and the pressure on the dies is equivalent to the difference in area between the two rams. The small ram I can also be attached to main ram, so that the intermediate sleeve H is locked to ram E, and moves with it, hence the pressure on the dies is now equivalent to the difference in area between ram E and intermediate sleeve H. For the maximum pressure the neutralizing rams are thrown out of service and the whole area of E is open to the pressure and the full load comes upon the dies. The cover F over the die slide contains the push-back plunger G, bearing directly upon the main plunger.

By this arrangement the three pressures can be obtained by a simple two-way valve, operated by the handle shown. The supply and exhaust pipes from the accumulator are as marked in the illustration.

The hydraulic pressure carried is 1500 pounds per square inch, and the machine has pressures of 50, 100 and 150 tons.

In Fig. 329 is shown a portable hydraulic riveter, which enables a large amount of work to be done in place. As can be seen in the cut, it can not only be swiveled in every direction, but can be suspended from a crane and thus traverse a large area. This machine

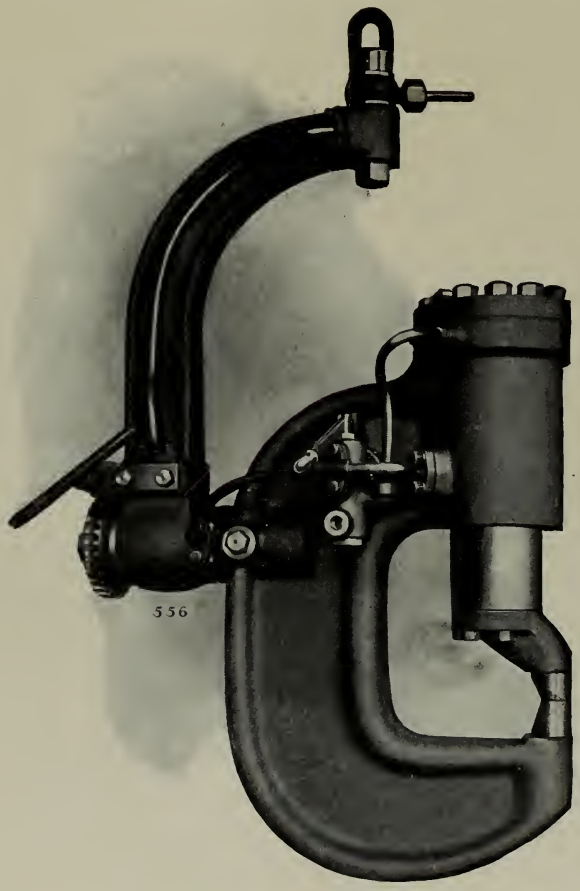

FIG. 329.

is much used for bridge work, ship structural and boiler work, and is also provided with double or treble power, as in the former case. In Fig. 330 is shown some of the applications of portable riveters to ship framing.

Pneumatic Riveting Machines.—There are many varieties of pneumatic riveting tools introduced within the last few years and have given good results, using rivets as large as 1¼ inches diameter. Of the different types in the market, the Boyer long stroke is

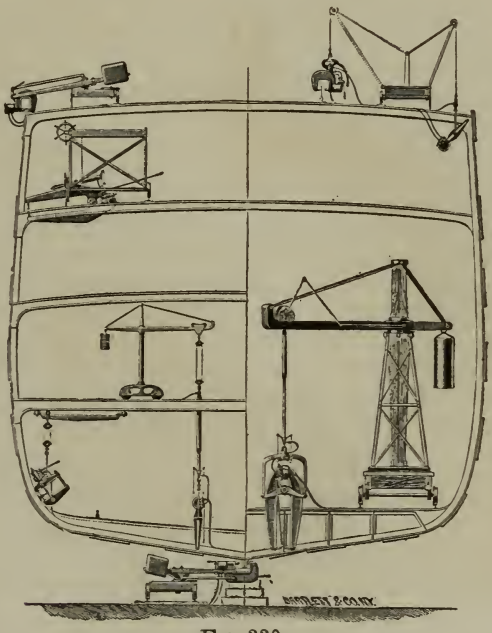

FIG. 330.

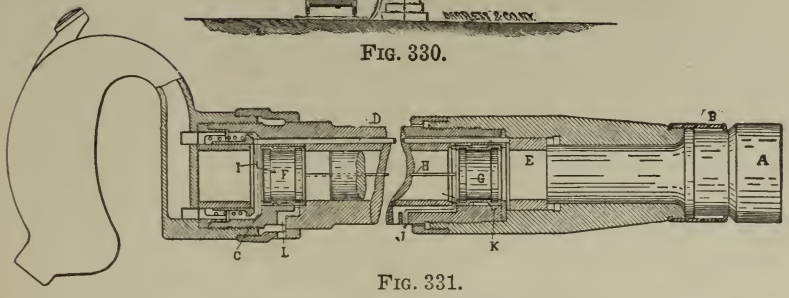

FIG. 331.

selected for illustration, as there is a section of this hammer in the Model Room, while in the practical drills this tool is employed in instruction.

Fig. 331 * shows the hammer with a riveting die *A* in position. Compressed air is admitted through a hose connected to the lower end of

* American Machinist, April 25, 1901.

the handle, the admission being controlled by a balanced piston valve conveniently placed for operation by the thumb of the operator. The opening of this valve alone is not, however, sufficient for starting the hammer. The blow of the piston is delivered directly on the shank of the die, which is prevented from falling out of the machine by a light clip *B* only. Should the air be turned on before the die is pressed against its rivet, the first blow would send the die and piston flying through the air, resulting in possible injury to some one or to the loss of the pieces. A second stop valve *C* is therefore employed which is operated by two rods, of which one is seen at *D*, which extend down through the body of the hammer, their lower ends resting on the ring *E* against which the die shank abuts. So long as the die is off its rivet the spring and air pressure behind valve *C* hold it firmly to its seat, the rod *D*, ring *E*, and die *A* being pushed to the right, and hence opening the thumb valve will not start the hammer. When, however, the die is pressed against the rivet, valve *C* is open and if the thumb valve be also open, the hammer will operate. Valve *C* is of course open wide or not at all, the control of the blow being entirely by the thumb valve. The operator is, in fact, unconscious of the presence of valve *C*. He only knows that the hammer must be in position for work before it will operate, and except for this fact the hammer behaves precisely as though there were no valve *C*.

The valves which control the blow of air to and from the two ends of the cylinder are shown at *F* and *G*, and are hollow, very light, and of short stroke. Light rods similar to but smaller than *D* lie between the valves in the walls of the cylinder. One of these rods is shown at *H*. As each valve moves towards the center of the cylinder, to admit air at its end, it through these rods pushes the other valve away from the center to exhaust the air from its end.

In the position of the parts shown, the air enters the upper end of the cylinder, as shown by the arrow *I*, and drives the piston downward, the exhaust escaping, as shown by the arrow *J*. As the lower end of the piston enters the valve *G*, it compresses the air before it. This cushion pressure, acting on the ring end of *G*, pushes it to the left, valve *F* being also pushed to the left through the action of rods *H*. In this position the ports which were previously opened are closed, while port *K* is opened to live air and port *L* to exhaust—the holes in which rods *D* lie serving also as passages to carry the air to port *K*. On the completion of the return stroke, the piston enters the upper valve *F*, when the action of the cushioned air is to push the valves to the right.

In connection with this tool a pneumatic *holder-on* is used and takes the place of the ordinary *dolly bar*, used when hand riveting, and is intended to hold the head end of the rivet up against the work, while the hammer is upsetting and forming the other end.

Its small size and light weight make it convenient for use in contracted places where the dolly bar can only be used with difficulty.

In Fig. 332 is shown the sectional view and elevation of the pneumatic *holder-on*. Compressed air enters the cylinder *A* through throttle valve *B* by means of rubber hose, the air inlet and exhaust valves being controlled by a knurled sleeve on the outside of the sleeve. A piston *C* and rod work within the cylinder, the piston rod having at its end a button set or cupping tool. On placing the set against the rivet head and opening the inlet valve, the piston, rod, and set are brought up against the rivet head and

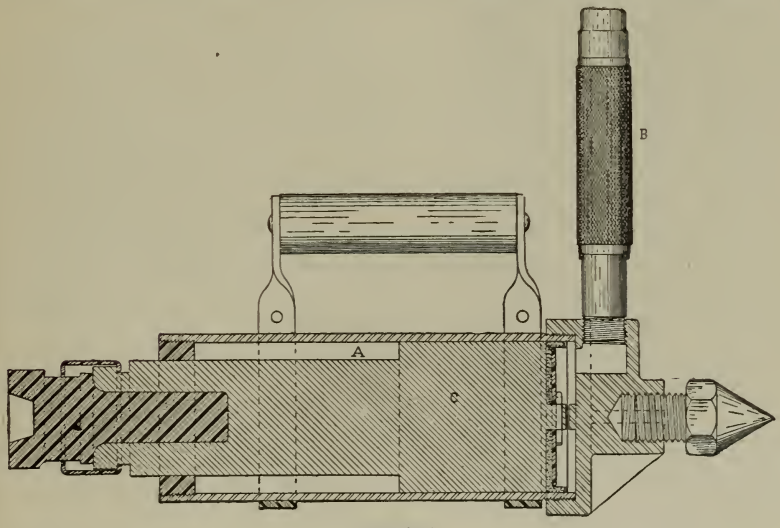

FIG. 332.

then the pneumatic riveter is put at work in forming the other end.

Other work, to which the pneumatic system is applied, is performed by pneumatic chipping hammers, beading, expanding, and calking tools, drills and hoists. Sectional models of these tools can be seen in the Model Room, while the connected machines are in operation in the different shops of the Engineering Building.

Of the drilling machines used in the boiler shop, the radial drill, gang and multiple drills, previously described, are exceedingly useful tools in boiler-making. Since, in the construction of cylindrical boilers, the building is done in position, portable drills are

used to some extent. In building up the shell of a boiler the plates, after bending, are temporarily connected, and the holes then drilled through the several plates in position by special drilling machines, so arranged that the boiler may be turned on the cradle or bed so as to present all portions of the surface to the drill as required.

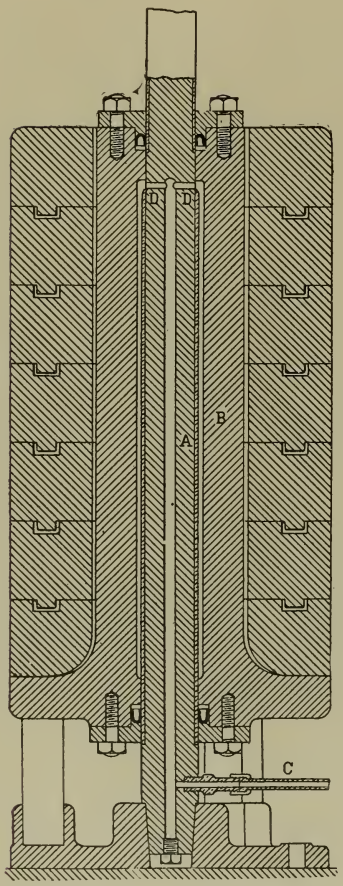

FIG. 333.

The Accumulator.—For the hydraulic transmission and distribution of power over a limited area for working machinery, such as riveters, flanging machines, cranes, etc., pressure is obtained by weights on a column of water instead of by elevation. For this purpose the *accumulator* was devised, and is simply a vertical cylinder containing a *ram* or *plunger* loaded with a weight. The area of the ram and the load placed upon it is governed by the pressure per square inch to be maintained in the hydraulic system. Heavy hydraulic pumps force water in the cylinder under the ram and lift it, hence the water in the cylinder, together with the pipe system leading from it are subject to that pressure. When the ram has reached the top of its stroke and the cylinder is full of water under pressure, an automatic gear connected to the throttle of the pumps shuts them down. When any hydraulic machine connected to the system is put in operation, water is expended but the pressure is maintained by the weighted ram. As the latter falls, the steam pump throttle valve is automatically opened and the supply of water kept up, the ram of the accumulator rising and falling

in accordance with the demands of the machines in operation and the pump supply. Thus, by means of the accumulator, an artificial head can be maintained in any part of a hydraulic system.

In Fig. 333 is shown an accumulator designed by Tweddell. In this case the ram A is fixed, while the cylinder B carries the weights and is movable, sliding upon the ram A, which acts as a guide. The water is pumped into the bottom of ram A, by means of pipe C, fills the annular space surrounding the ram or guide, and the whole weight is lifted by the water acting on the annular area D.

Steam pressure on one side of a piston is also used instead of a direct weight, and acts upon a water plunger or ram, and is much used in naval hydraulic installations.

The standard working pressure for hydraulic machinery is 1500 pounds per square inch.

The amount of energy stored in an accumulator will be:

Foot pounds

$$= 2240\ WL = \frac{\pi d^2}{4} PL.$$

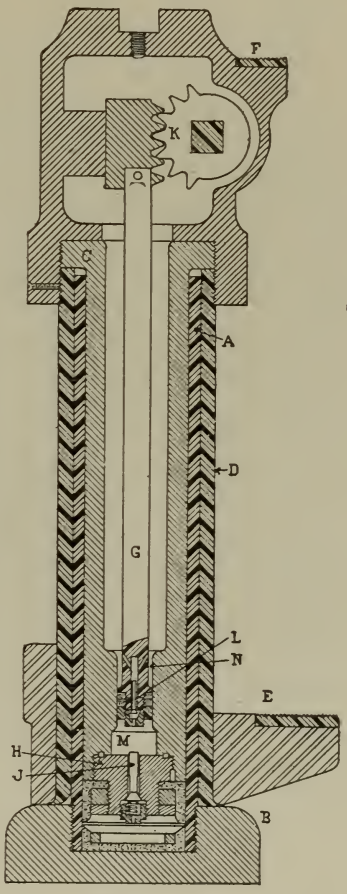

FIG. 334.

Where

W = weight on ram, in tons,
d = diameter of ram, in inches,
P = pressure in pounds, per square inch,
L = vertical lift of the ram.

Taking a 12-inch accumulator with a lift of 20 feet and working

pressure of 1500 pounds per square inch, the plunger being at the top of the stroke:

Energy stored $= 113.097 \times 1500 \times 20 = 3{,}392{,}910$ foot pounds.

$\frac{3392910}{33000} = 102.81$ horse power per minute.

The Hydraulic Jack.—An essential tool in engineering workshops, and with the erecting force, is the hydraulic jack, and consists of a fixed hydraulic cylinder *A* secured to the base plate *B*, Fig. 334. Within the cylinders slides the ram *C*, secured at its top to the head of the jack, and over the hydraulic cylinder slides the claw tube *D*, carrying the lower claw *E*, to take hold of the work to be lifted. A top claw *F* is also fitted and is a part of the head. Within the hollow ram, at its lower end, works a piston *G*, fitted with a non-return valve *L*, and the bottom of the ram is closed by a plug *H*, fitted with a delivery non-return valve *J*. The piston is connected by the piston rod to the rack and pinion *K*, and operated by a lever on the axis of the pinion.

The operation of the jack is as follows: Water or oil is carried in the hollow head, and by motion of the outside lever which works the piston, the water flows through the suction valve *L*, and forced through the delivery valve *J*, into the lower part of the hydraulic cylinder. Pressure is thus exerted on the ram and it rises, together with any load upon it. When it is required to lower the jack, the handle is reversed, giving a longer stroke downward, causing the end of the piston rod to force open the delivery valve, and allowing the water to flow back into the cavity *M*, thence to the reservoir via the cavity *N*, which is now open to *M*.

APPENDIX

HIGH-SPEED STEELS.

The term *high speed* should not be considered as relating alone to the linear speed of the material under the tool, since the principal point is the increased speed at which a given piece of work can be performed, or the amount of material which can be removed in a given time. Steel known as *air hardening or self hardening*, as a rule, is not tough, that is, if it is tough it will not be very hard. The edge of the tool will flow, and if made so hard that it will not flow, then it is so brittle that it crumbles easily and hence limits its usefulness.

In the experiments and tests which resulted in the production of the present high-speed steels, which are entirely different from the former air-hardening steels, manganese has been reduced from 3 and 4 percent to 0.30 percent, and less; tungsten has been increased up to 10 and even 20 percent, from the former 5 and 6 percent, and the carbon is generally less than one percent.

There are a number of different brands on the market, each one claiming particular advantages. An analysis of two of the leading brands is given below:

	Percent.		Percent.
Tungsten	9.99		18.48
Chrome	2.83		2.90
Carbon	0.69		0.78
Phosphorus	0.010		....
Sulphur	0.010		....
Silicon	Trace		....
Manganese	Trace		0.33

Another contains the following:

	Percent.		Percent.
Molybdenum	9.65	Phosphorus	0.016
Chromium	...	Silicon	0.046
Carbon	0.66	Manganese	0.22

All traditions as to heating are completely reversed, one brand is famous for its excellence in one kind of work, another in another kind, no one yet seeming to cover all the ground.

There are many records published of the work done by this steel, giving speed per minute, feed, depth of cut, etc. Of these one or two

instances are mentioned to illustrate some of the work that may be done.

Two tools are used on a 9-inch forged-steel shaft with a cutting speed of 125 feet per minute, $\frac{1}{2}$-inch cut and $\frac{1}{12}$-inch feed, giving 62.5 cubic inches or 17.5 pounds of metal removed per minute, or 1050 pounds per hour. A Lodge & Shipley lathe ran with three cutting tools on 50-carbon steel, with an aggregate depth of cut of 3 inches, $\frac{1}{16}$-inch feed and 50 feet per minute cutting speed, thus removing 113 cubic inches per minute, or 1898.4 pounds of metal per hour. The *Engineer*, of London, speaks editorially of a single tool which cut 1875 pounds of metal per hour.

Among the curious things that have been developed by the increasing use of high-speed steel, is the apparent fact that these steels are not nearly as advantageous for use in planers as they are in lathes. Such steels have been repeatedly tried in planers with arrangements for speeding the platen up to something like the speed obtained in lathe work, and in no case heard of, have the tools been able to stand anything like the speed which they easily stand in the lathe. Apparently, the only way of accounting for this is the fact that the action of the tool in the planer is intermittent, and that during the return stroke opportunity is given for the diffusion through the tool, with a consequent lowering of temperature at the cutting point. The alternate heating and cooling thus produced, appears to be the only thing which can account for the fact that the attainable speed is no where near as high as can readily be obtained with the same tool used in the lathe.

There is quite an amount yet to be learned regarding the best method of hardening; for very high speeds it seems to be necessary to fairly melt the point of the tool, quench it in a strong air blast, and then grind to shape, this will not answer for dies, milling cutters, etc., on account of the heat destroying the tools. These tools are finished from annealed bars; the high-speed steel being capable of annealing as readily as carbon steel, and in this respect differs entirely from air-hardening steel.

The finished tools are heated in a lead bath of 1800° to 2000°, and quenched quickly in ordinary tempering oil kept cool by a coil and circulating water. They are then tempered in a bath of heavy oil heated to about 450°.

THERMIT.

Thermit is the name given to mixtures of finely divided aluminum with metallic oxides, sulphides, chlorides, etc., in order to effect a reduction of metals with which oxygen, sulphur, or chlorine combine. When the powdered aluminum is mixed with the bodies named and then ignited, the aluminum has such a powerful affinity for oxygen, that in

the process of oxidation an enormous heat is evolved. This temperature is so high that many metals ordinarily infusible can be reduced and obtained in a compact form. The temperature of the reaction is estimated to be about 5400 degrees Fahrenheit (about 3000 degrees centigrade), and at the same time, owing to the absence of carbon, it is possible to obtain many metals by this process, with a degree of purity hitherto unknown.

The aluminum-thermit process can be summarized in first, using the metal reduced out of the compound; secondly, using the heat generated only; and third, a combination of both. The first part being purely metallurgical, by which free carbon, pure chromium, manganese, nickel, and other metals are produced, is not directly of importance to the naval engineer and shipbuilder. The process has been developed for butt welding of any shape, or of any weldable material, so that angles, tee-bars, and tram-rail joints can be readily and quickly made so as to be practically in one piece. In places where riveting is not practicable, the welding of joints of angles, beams, etc., is made possible. For breaks about the shafting of marine engines, stern posts, struts, connecting rods, etc., the damage has been repaired with economy and dispatch by this process, shafts up to 12 inches in diameter having been successfully welded in one operation. The applications of thermit lend themselves especially to the junctions of sections of wrought iron or steel pipes for steam, hydraulic, compressed air, and refrigerating machinery, instead of the use of flanges and couplings.

In the foundry heavy castings which have been cracked, or which have not come out of the mould in good condition, have been successfully mended by the application of thermit, while piping in steel ingots is prevented by plunging a charge of thermit into the ingot. The reaction and consequent reheating of the mass commences immediately, and the temperature generated remelts that inner part of the metal which was just on the point of solidifying, and destroys the piping.

Since thermit melts out about half its weight in metallic iron, small castings can be made in an emergency without the aid of a cupola, and in general for quick repair at sea, it will prove of considerable help in the Engineering Department.

In the above operations the metallic oxide used with aluminum is iron oxide. If a small spot on the thermit can be sufficiently heated it will start the reaction which will go on and pass through the whole mass. The ignition is usually started by means of a small portion of magnesium and if the constituents are mixed in the proper proportions, the aluminum will be burned to aluminum oxide, by extracting the oxygen from the iron oxide, leaving the iron in a pure state, which is in reality melted wrought iron or low-carbon steel, and which can be cast into moulds. This has been named *thermit iron* by the inventor Dr. Goldschmidt, and it may be modified, if desired, by the admixture with

the thermit of small quantities of manganese, chromium or other metals, or it may be carbonized by the addition to the mixture in the crucible or ladle, of high-carbon steel or cast iron. The temperature is so high that in any case it is better to reduce it, and in the case of thermit iron, it is usually done by the addition of about 10 percent of iron

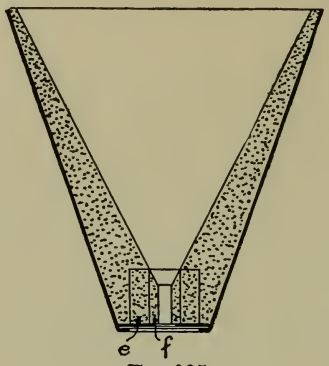

FIG. 335.

punchings, particularly when the metal is to be used for welding purposes.

The thermit reaction takes place in a crucible, Fig. 335, having at its bottom a hard magnesian stone *e* with a tubular opening into which

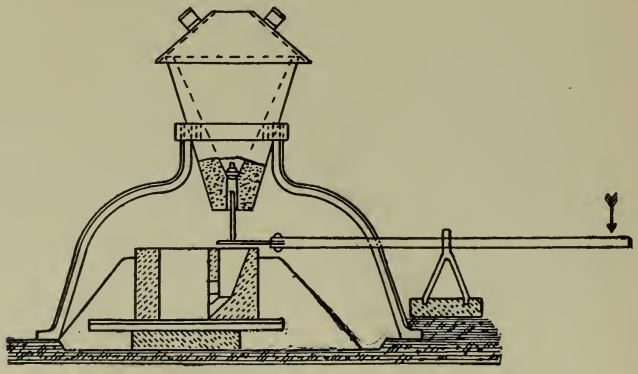

FIG. 336.

a small conical magnesia thimble *f* is made to fit and covers the outlet for the liquid thermit, this outlet not exceeding $\frac{1}{2}$ inch in diameter. The crucible consists of a conical sheet-iron shell, lined with a suitable refractory material. The opening in the thimble is closed as follows: A tapping pin, Fig. 336, is suspended by its scarfed end inside the thimble, and through the bottom of the crucible. The top of the thimble

is then closed with an asbestos washer and metal disc, and then covered over with magnesite sand. Extending from the lower end of the tapping pin is a long lever and on striking the outer end with a smart tap, the tapping pin is driven upwards and the contents of the crucible will then run out through the thimble or tapping hole.

On charging the crucible, the thermit powder is poured in to form a level surface, and in the center of this surface is placed a small amount of *ignition powder*, which is ignited by applying a storm match. The chemical reaction is started immediately and is completed in less than a half minute. The result is a pure liquid steel (thermit steel), which sinks to the bottom of the crucible and is covered by a distinct layer of aluminum slag, called corundum. The iron is equal in weight to the slag but occupies but one-third of its cubic space. Its weight is

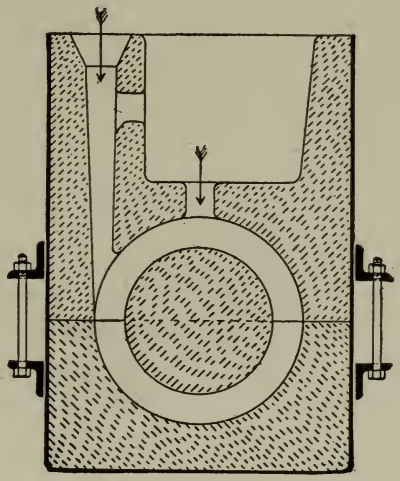

FIG. 337.

one-half that of the thermit powder. When the reaction is completed the crucible is emptied into the mould through the tapping hole.

When large quantities are being operated upon it is advisable to mix small clean steel punchings into the thermit powder, the intensity of the heat is thereby moderated without interfering with the efficiency of the weld. The addition of about one-half percent of manganese is sometimes advisable.

The proper shape of the *mould* is of the utmost importance. Equal parts of sharp sand and common clay are used in its composition and the mould must be very thoroughly dried out and baked, to completely burn out the chemically combined water in the clay. It must be provided with a riser and overflow gates just above the level the liquid is to reach, through which the liquid slag is diverted and kept apart from

the thermit iron, see Fig. 337 showing the mould for repairing a fractured shaft, and Fig. 338, the mould for welding girders. The surface of the metal to be operated upon must be free from rust or grease and must be warmed, but not exceeding a dull red heat. Since 41 ounces of liquid steel will fill one cubic inch and thermit gives half its weight in the form of liquid steel, 9 ounces must be calculated for each cubic inch to be filled, but for large and important welds twice the amount should be allowed.

When two pieces are to be joined together, the thermit steel is run between and around the end in the shape of a ring. In some cases the liquid thermit cannot and need not be run in between the ends, the ring welded around the joint being sufficient.

As applied to foundry practice, the thermit powder wrapped in paper is dropped on the liquid metal as it rises in the riser, and before it gets into the rising head. When applied to *cast iron* the thermit parcel must contain at its bottom a small quantity of ignition powder. For

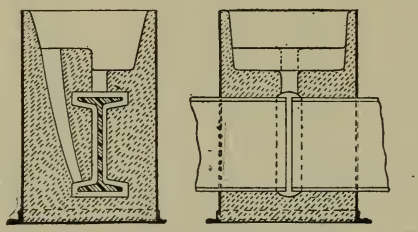

FIG. 338.

liquid steel the ignition powder is superfluous, as liquid steel is hot enough to ignite thermit. This addition is made without danger and does not interfere with the chemical or physical properties of the casting.

If a casting is wanted in a hurry, it can be readily made by using thermit with 20 percent of small punchings added. This is run through the mould in the usual way, no cupola or furnace being required.

With faulty castings, for instance, in the case of a crack this has to be widened in order to let sufficient of the thermit iron run in. This superheated metal will soften up the inner walls of the crack and unite with them so perfectly as to make one piece. By this means a casting that would probably have to be discarded can be rendered sound and serviceable at a slight expense.

Probably the most extensive use to which this process has been put is the bonding or welding of steel car rails, for producing a continuous rail for electric traction purposes. This is performed as follows: A simple mould is placed around the rails at the joints, after the ends have been thoroughly cleaned and dried, and the two parts secured

together by clamps. When all is ready the required charge in the crucible is ignited, and as soon as it is in a molten state, the crucible is tapped and the metal run into the mould. When the metal is set the mould is knocked away. The thermit steel actually melts the ends of the rail ends exposed in the mould, and amalgamates itself with the steel of the rail until it is one solid mass, with no longer the semblance of a joint except at the top of the rail where pains are taken to avoid welding. A similar plan is adopted for welding pipe ends, the two ends being butted together as in the case of rails and the mould built around the junction.

An interesting case of the repair of the broken stern frame of an ocean-going steamer due to collision was reported by *Engineering*. The section at the place repaired was 11 inches by $6\frac{3}{4}$ inches and the frac-

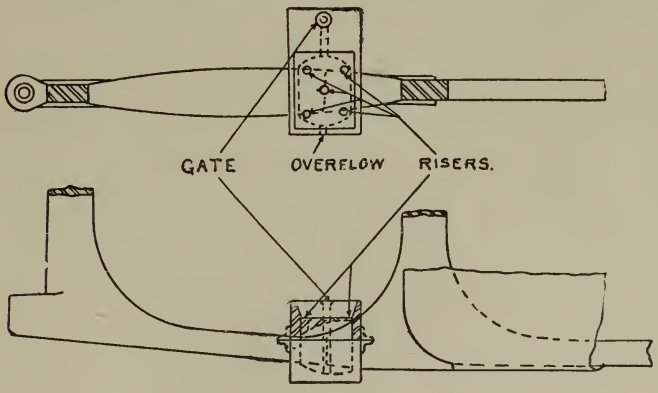

FIG. 339.

ture was widened 1 inch to give the welding iron a chance to run into the fracture. A strengthening ring 2 inches thick by 6 inches in width was cast around the break, using about 700 pounds of iron in the completed operation.

The mould, Fig. 339, consisted of a divided box of sheet iron lined with a high refractory lining, was placed about the fractured part of the frame. The frame was heated in the vicinity of the break to a red heat and the thermit metal then poured into the mould and the weld effected, the mould being allowed to remain in place for four hours. As the amount of metal used was large, the slag was allowed to flow over the rim of the mould into a dry sand bed. The iron in the runner, as well as the risers, was in one piece with the weld and could not be broken off with sledges and a ram, but had to be cut away. Two small holes drilled through the weld showed satisfactory density. Afterwards the weld and neighboring parts of the stern post were annealed in a charcoal fire for twenty hours. The cost of the repairs amounted

to less than $1000 and the vessel has made a number of Transatlantic trips in good condition.

A fact to be noted in connection with the pouring of thermit iron and steel is that it cannot be poured over the lip of the ladle, if any of the slag is allowed to go first, for wherever the slag touches, it will stick and prevent the steel from adhering to any surface covered by the slag. This is the reason that bottom tapping is resorted to in this process.

In the Practical Drills in the Engineering Building, illustrations of the application of thermit in welding and in foundry work are given on a small scale.

EXTRACT FROM BUREAU OF STEAM ENGINEERING MACHINERY SPECIFICATIONS FOR STEEL SHIPS.

The characteristics of steel, referred to in the following as classes A, B, and C, can be seen in *Naval Engines and Machinery*, or in Navy Department Circulars for the inspection of steel for naval purposes.

BOLTS, NUTS, SCREWS, AND WASHERS.

The material of various bolts, studs, etc., will be as follows:

Bolts, studs, etc., in—	Material
Crank-pin caps; crosshead-pin caps; eccentric sheaves, straps and rods; piston and piston valve followers; main links; all moving parts of main engines	High-grade forgings.
Shaft couplings; main-bearing caps; thrust-bearing side rods; main-engine framing; moving parts of circulating-pump engines and forced-draft blower engines	"Class A" forgings.
All cylinder and valve-chest covers; all bolts not otherwise mentioned, securing together various parts of machinery; all pipe flanges whatsoever; all valve bonnets	"Class A" bolt material.
Pipes and valves beneath floor plates	"Class A" bolt material, composition nuts.
Bolts and studs for structural purposes where strength is not a prime requisite	Either "Class A" or "Class B" bolt material.
Studs for valve glands	Rolled bronze, composition nuts.
Condensers	Rolled manganese, phosphor or Tobin bronze.
Propeller blades	Rolled manganese or Tobin bronze.
Set screws	"Class A" forgings, casehardened.
Steel washers	"Class B" material.

All bolts less than 3 inches in diameter will have heads, nuts, and screw threads to conform to the United States Navy standard. All bolts 3 inches diameter and above will have four threads per inch of the standard form, except in special cases, which will be submitted for approval.

Threads of all bolts, nuts, and screws must be clean, sharp, and well fitting. The threads of classes A and B bolts may be either chased or cut with a die, but the threads of body-bound bolts must be chased and must extend far enough down so that when the nut is screwed home there will not be more than one and one-half threads under it. The plain part of body-bound bolts must be turned in a lathe to fit accurately in the bolt hole.

The heads and bodies of bolts must be concentric.

All bolt holes in permanently fitted parts will be reamed or drilled fair and true in place, and the bodies of bolts finished to fit them snugly.

All bolts for securing the boiler attachments will, where possible, be screwed through the boiler plates, with heads inside.

All finished bolts, except as directed, will be kept from turning by dowels or other suitable devices.

All studs used in moving parts, and elsewhere as required, will be collar studs and will be secured in an approved manner. Studs and nuts will always be used in preference to tap bolts where possible.

All bolts, nuts, and keys on moving parts and on pillow blocks, and elsewhere as shown, will be carefully secured from working loose. The nuts will be locked and the bolts will extend beyond the nuts, without threads, and will be fitted with split pins.

Where the end of a bolt is turned down and has a hole drilled in it for reception of split pin or cotter pin, it must be turned to a smaller diameter than bottom of thread.

All nuts, unless otherwise specified, will be of steel or wrought iron. All nuts that require frequent taking off and setting up will be of wrought iron, well casehardened.

All nuts will be hot-pressed or cold punched and reamed before threading, the holes to be central and square with faces. All nuts must fit on the bolts without shake.

Nuts to be used about machinery must fit so tight that it will be necessary to use a wrench to turn them. All other nuts must be at least thumb-tight.

MATERIALS AND WORKMANSHIP.

All material used in the construction of the machinery will be of the best quality.

Cast-steel pipe fittings will be "Class B."

Iron castings will be made of the best pig iron, not scrap, except where otherwise directed.

No imperfect casting or unsound forging will be used if the defect affects the strength or, to a marked degree, its sightliness.

All castings will be sound and true to form, and before being painted will be well cleaned of sand and scale and all fins and roughness removed.

All castings will be increased in thickness around core holes. Core holes will be tapped, and core plugs screwed in and locked, except where bolted covers are used, or where it may be directed that the holes be left open.

All nuts on rough castings will fit facings raised above the surface, except where otherwise directed. All flanges of castings will be faced, and those coupled together will have their edges made fair with each other.

The faces of all circular flanges will be grooved.

All flanges, collars, and offsets will have well-rounded fillets.

All flanged parts of boilers will be annealed after flanging, in an approved manner.

All boiler plates and stays will be well cleaned of mill scale, by pickling or other approved means.

All steel forgings will be without welds and free from laminations.

All "high-grade" steel forgings 5 inches and more in diameter will have axial holes of approved diameter.

The working parts of all auxiliary machinery, unless otherwise specified, will be made of "Class A" forgings.

All steel piston rods and valve stems of auxiliary engines will be oil-tempered.

All steel joint pins of valve gear will be hardened and ground to true cylindrical surfaces.

All small pins of working parts will be well casehardened.

All eyes in levers and brackets will be bushed, if required.

All brasses will fit loosely between collars of shafting.

All brasses of journals will be properly channeled for the distribution of oil.

Composition castings will be made of new materials.

The various compositions will be as follows:

	Copper	Tin	Lead	Zinc
For all journal boxes and guide gibs, where not otherwise specified: by weight	6 parts	1 part	....	$\frac{1}{4}$ part
Naval brass	62 percent	1 percent	....	37 percent
Brazing metal and flanges for copper pipes	85 percent	....	....	15 percent
All angle, globe, and check valves for steam and general purposes not otherwise specified	At least 87 percent	At least 7 percent	Not over 2 percent	Remainder
Condenser tubes	70 percent	1 percent	....	29 percent
Pipe fittings and composition not otherwise specified	88 percent	10 percent	....	2 percent

Antifriction metal will be of the following composition:

Best refined copper....	3.7 percent	To be well fluxed with borax and rosin in mixing
Banca tin.....	88.8 percent	
Regulus of antimony ..	7.5 percent	

Ornamental brass fittings will be of good, uniform color.

All work will be in every respect of the first quality, and executed in a workmanlike and substantial manner.

Any portion of the work, whether partially or entirely completed, found defective, must be removed and satisfactorily replaced without extra charge.

ALLOYS AND COMPOSITIONS.

For alloys and compositions there does not appear to be any standard formulæ among manufacturers. The mixtures vary largely in proportion to the price and purposes for which the alloy is to be used. The following table is made up from standard proportions as far as they could be obtained.

Alloys	Copper	Tin	Zinc	Lead	Antimony	Iron	Aluminum	Nickel
U. S. Navy Dept. bearings and gibs..	82.8	13.8	3.4	....	....	....	..	...
U. S. Navy composition	88	10	2	....	....	....	..	...
Naval brass.....	62	1	37	....	....	....	..	...
Tobin bronze.....	59	2.16	38.40	0.31	....	0.11	..	...
Delta metal.....	60	1 to 2	34 to 44	....	....	2 to 4	..	...
Admiralty metal....	87	8	5	....	....	....	..	...
Gun metal.....	92.5	5	2.5	....	....	....	..	...
Gun metal.....	87.75	9.75	2.5	....	....	....	..	...
Muntz metal.....	60	.....	40	....	....	....	..	...
Locomotive bearings Penn. R. R.....	77	8	.....	15	....	....	..	...
Machinery bearings..	87.5	12.5	.....	....	....	....	..	...
Phosphor bronze...	92	8 phosphoret of tin			....	....	..	...
Manganese bronze...	88.6	8.7	1.6	.3	....	.7	..	...
Aluminum bronze...	90	.....	.....	....	....	....	10	...
German silver.....	51.6	22.6	.....	....	....	....	..	25.8
Nickel silver.....	75	.....	.....	....	....	....	..	25
Babbitt metal.....	3.6	89.3	.....	....	7.1	....	..	...
Parsons' metal.....	2	86	27	2	1	....	..	...
Richards' metal.....	4.5	70	.....	10.5	15	....	..	. .
Fentons' metal.....	5	16	79	....	....	....	..	...
SOLDERS							..	...
Common	.....	40	.....	60	....	....	..	...
Fine	.....	66	.....	34	....	....	..	..
Spelter, soft.....	50	.....	50	....	....	....	..	...
Spelter, hard.....	65	.....	35	....	....	....	.	...
Lead	33	.....	.....	67	*Silver*	*Cadmium*	..	.. .
Silver, hard.....	20	.....	.....	....	80	....	..	...
Silver, soft.....	12	.....	.....	....	67	21	..	...

DECIMAL EQUIVALENTS OF PARTS OF AN INCH.

1-64	.015625	33-64	.515625
1-32	.03125	17-32	.53125
3-64	.046875	35-64	.546875
1-16	.0625	9-16	.5625
5-64	.078125	37-64	.578125
3-32	.09375	19-32	.59375
7-64	.109375	39-64	.609375
1-8	.1250	5-8	.6250
9-64	.140625	41-64	.640625
5-32	.15625	21-32	.65625
11-64	.171875	43-64	.671875
3-16	.1875	11-16	.6875
13-64	.203125	45-64	.703125
7-32	.21875	23-32	.71875
15-64	.234375	47-64	.734375
1-4	.2500	3-4	.7500
17-64	.265625	49-64	.765625
9-32	.28125	25-32	.78125
19-64	.296875	51-64	.796875
5-16	.3125	13-16	.8125
21-64	.328125	53-64	.828125
11-32	.34375	27-32	.84375
23-64	.359375	55-64	.859375
3-8	.3750	7-8	.8750
25-64	.390625	57-64	.890625
13-32	.40625	29-32	.90625
27-64	.421875	59-64	.921875
7-16	.4375	15-16	.9375
29-64	.453125	61-64	.953125
15-32	.46875	31-32	.96875
31-64	.484375	63-64	.984375
1-2	.5000	1	1.

SIZES OF TAP DRILLS FOR U. S. STANDARD THREADS.

By the formulas given below, the results, strictly speaking, are the diameters of the bottoms of the threads. The tap drill is, in common practice, the one that is one or two gage numbers larger, for the smaller, or numbered sizes, and one that is about .005 inch larger for the larger sizes. The amount allowed for clearance varies in different shops and on different classes of work.

Size of tap drill of U. S. standard thread = outside diameter of screw $- \frac{1.299}{\text{threads to the inch.}}$

Size of tap drill for $\frac{3}{4}$-inch screw, U. S. Standard thread, 10 threads to the inch $= .750 - \frac{1.299}{10} = .750 - .1299 = .6201$, size of tap drill.

Diameter of screw.	Threads per inch.	Size of tap drill.	Diameter of screw.	Threads per inch.	Size of tap drill.
1-4	20	.185	2	4 1-2	1.712
5-16	18	.240	2 1-4	4 1-2	1.962
3-8	16	.294	2 1-2	4	2.176
7-16	14	.344	2 3-4	4	2.426
1-2	13	.400	3	3 1-2	2.629
9-16	12	.454	3 1-4	3 1-2	2.879
5-8	11	.507	3 1-2	3 1-4	3.100
3-4	10	.620	3 3-4	3	3.317
7-8	9	.731	4	3	3.567
1	8	.837	4 1-4	2 7-8	3.798
1 1-8	7	.940	4 1-2	2 3-4	4.028
1 1-4	7	1.065	4 3-4	2 5-8	4.256
1 3-8	6	1.160	5	2 1-2	4.480
1 1-2	6	1.284	5 1-4	2 1-2	4.730
1 5-8	5 1-2	1.389	5 1-2	2 3-8	4.953
1 3-4	5	1.491	5 3-4	2 3-8	5.203
1 7-8	5	1.616	6	2 1-4	5.423

SIZES OF TAP DRILLS FOR V THREADS.

Size of tap drill for V thread = outside diameter of screw $- \frac{1.732}{\text{threads to the inch.}}$

Size of tap drill for $\frac{3}{4}$-inch V thread, 10 threads to the inch $= .750 - \frac{1.732}{10} = .750 - .1732 = .5768$, size of tap drill.

SIZES OF NUMBERS OF THE U. S. STANDARD GAGE FOR SHEET AND PLATE IRON AND STEEL.

AN ACT ESTABLISHING A STANDARD GAGE FOR SHEET AND PLATE IRON AND STEEL.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That for the purpose

of securing uniformity the following is established as the only gage for sheet and plate iron and steel in the United States of America, namely:

Number of gage.	Approximate thickness in fractions of an inch.	Approximate thickness in decimal parts of an inch.	Weight per square foot in ounces avoirdupois.	Weight per square foot in pounds avoirdupois.
0000000	1-2	.5	320	20.00
000000	15-32	.46875	300	18.75
00000	7-16	.4375	280	17.50
0000	13-32	.40625	260	16.25
000	3-8	.375	240	15.
00	11-32	.34375	220	13.75
0	5-16	.3125	200	12.50
1	9-32	.28125	180	11.25
2	17-64	.265625	170	10.625
3	1-4	.25	160	10.
4	15-64	.234375	150	9.375
5	7-32	.21875	140	8.75
6	13-64	.203125	130	8.125
7	3-16	.1875	120	7.5
8	11-64	.171875	110	6.875
9	5-32	.15625	100	6.25
10	9-64	.140625	90	5.625
11	1-8	.125	80	5.
12	7-64	.109375	70	4.375
13	3-32	.09375	60	3.75
14	5-64	.078125	50	3.125
15	9-128	.0703125	45	2.8125
16	1-16	.0625	40	2.5
17	9-160	.05625	36	2.25
18	1-20	.05	32	2.
19	7-160	.04375	28	1-75
20	3-80	.0375	24	1.50
21	11-320	.034375	22	1.375
22	1-32	.03125	20	1.25
23	9-320	.028125	18	1.125
24	1-40	.025	16	1.
25	7-320	.021875	14	.875
26	3-160	.01875	12	.75
27	11-640	.0171875	11	.6875
28	1-64	.015625	10	.625
29	9-640	.0140625	9	.5625
30	1-80	.0125	8	.5
31	7-640	.0109375	7	.4375
32	13-1280	.01015625	6 1-2	.40625

Number of gage.	Approximate thickness in fractions of an inch.	Approximate thickness in decimal parts of an inch.	Weight per square foot in ounces avoirdupois.	Weight per square foot in ounces avoirdupois.
33	3-320	.009375	6	.375
34	11-1280	.00859375	5 1-2	.34375
35	5-640	.0078125	5	.3125
36	9-1280	.00703125	4 1-2	.28125
37	17-2560	.006640625	4 1-4	.265625
38	1-160	.00625	4	.25

And on and after July first, eighteen hundred and ninety-three, the same and no other shall be used in determining duties and taxes levied by the United States of America on sheet and plate iron and steel. But this act shall not be construed to increase duties upon any articles which may be imported.

SEC. 3. That in the practical use and application of the standard gage hereby established a variation of two and one-half percent, either way may be allowed. Approved March 3, 1893.

WEIGHT OF IRON AND STEEL SHEETS.

WEIGHTS PER SQUARE FOOT.—Kent.

Thickness by Birmingham gage.				Thickness by American (Brown and Sharpe's) gage.			
No. of gage.	Thickness in inches.	Iron.	Steel.	No. of gage.	Thickness in inches.	Iron.	Steel.
0000	.454	18.16	18.52	0000	.46	18.40	18.77
000	.425	17.00	17.34	000	.4096	16.38	16.71
00	.38	15.20	15.30	00	.3648	14.59	14.88
0	.34	13.60	13.87	0	.3249	13.00	13.26
1	.3	12.00	12.24	1	.2893	11.57	11.80
2	.284	11.36	11.59	2	.2576	10.30	10.51
3	.259	10.36	10.57	3	.2294	9.18	9.36
4	.238	9.52	9.71	4	.2043	8.17	8.34
5	.22	8.80	8.98	5	.1819	7.28	7.42
6	.203	8.12	8.28	6	.1620	6.48	6.61
7	.18	7.20	7.34	7	.1443	5.77	5.89
8	.165	6.60	6.73	8	.1285	5.14	5.24
9	.148	5.92	6.04	9	.1144	4.58	4.67
10	.134	5.36	5.47	10	.1019	4.08	4.16
11	.12	4.80	4.90	11	.0907	3.63	3.70
12	.109	4.36	4.45	12	.0808	3.23	3.30
13	.095	3.80	3.88	13	.0720	2.88	2.94
14	.083	3.32	3.39	14	.0641	2.56	2.62
15	.072	2.88	2.94	15	.0571	2.28	2.33
16	.065	2.60	2.65	16	.0508	2.03	2.07
17	.058	2.32	2.37	17	.0453	1.81	1.85

Thickness by Birmingham gage.				Thickness by American (Brown and Sharpe's) gage.			
No. of gage.	Thickness in inches.	Iron.	Steel.	No. of gage.	Thickness in inches.	Iron.	Steel.
18	.049	1.96	2.00	18	.0403	1.61	1.64
19	.042	1.68	1.71	19	.0359	1.44	1.46
20	.035	1.40	1.43	20	.0320	1.28	1.31
21	.032	1.28	1.31	21	.0285	1.14	1.16
22	.028	1.12	1.14	22	.0253	1.01	1.03
23	.025	1.00	1.02	23	.0226	.904	.922
24	.022	.88	.898	24	.0201	.804	.820
25	.02	.80	.816	25	.0179	.716	.730
26	.018	.72	.734	26	.0159	.636	.649
27	.016	.64	.653	27	.0142	.568	.579
28	.014	.56	.571	28	.0126	.504	.514
29	.013	.52	.530	29	.0113	.452	.461
30	.012	.48	.490	30	.0100	.400	.408
31	.01	.40	.408	31	.0089	.356	.363
32	.009	.36	.367	32	.0080	.320	.326
33	.008	.32	.326	33	.0071	.284	.290
34	.007	.28	.286	34	.0063	.252	.257
35	.005	.20	.204	35	.0056	.224	.228

	Iron.	Steel.
Specific gravity	7.7	7.854
Weight per cubic foot	480.	489.6
Weight per cubic inch	.2778	.2833

As there are many gages in use differing from each other, and even the thicknesses of a certain specified gage, as the Birmingham, are not assumed the same by all manufacturers, orders for sheets and wires should always state the weight per square foot, or the thickness in thousandths of an inch.

WEIGHTS AND AREAS OF SQUARE AND ROUND BARS OF WROUGHT IRON, AND CIRCUMFERENCES OF ROUND BARS.

One Cubic Foot Weighing 480 Pounds.

Thickness or diameter in inches.	Weight of □ bar one foot long.	Weight of ○ bar one foot long.	Area of □ bar in square inches.	Area of ○ bar in square inches.	Circumference of ○ bar in inches.
1-16	.013	.010	.0039	.0031	.1963
1-8	.052	.041	.0156	.0123	.3927
3-16	.117	.092	.0352	.0276	.5890
1-4	.208	.164	.0625	.0491	.7854

Thickness or diameter in inches.	Weight of □ bar one foot long.	Weight of ○ bar one foot long.	Area of □ bar in square inches.	Area of ○ bar in square inches.	Circumference of ○ bar in inches.
5-16	.326	.256	.0977	.0767	.9817
3-8	.469	.368	.1406	.1104	1.1781
7-16	.638	.501	.1914	.1503	1.3744
1-2	.833	.654	.2500	.1963	1.5708
9-16	1.055	.828	.3164	.2485	1.7671
5-8	1.302	1.023	.3906	.3068	1.9635
11-16	1.576	1.237	.4727	.3712	2.1598
3-4	1.875	1.473	.5625	.4418	2.3562
13-16	2.201	1.728	.6602	.5185	2.5525
7-8	2.552	2.004	.7656	.6013	2.7489
15-16	2.930	2.301	.8789	.6903	2.9452
1	3.333	2.618	1.0000	.7854	3.1416
1-16	3.763	2.955	1.1289	.8866	3.3379
1-8	4.219	3.313	1.2656	.9940	3.5343
3-16	4.701	3.692	1.4102	1.1075	3.7306
1-4	5.208	4.091	1.5625	1.2272	3.9270
5-16	5.742	4.510	1.7227	1.3530	4.1233
3-8	6.302	4.950	1.8906	1.4849	4.3197
7-16	6.888	5.410	2.0664	1.6230	4.5160
1-2	7.500	5.890	2.2500	1.7671	4.7124
9-16	8.138	6.392	2.4414	1.9175	4.9087
5-8	8.802	6.913	2.6406	2.0739	5.1051
11-16	9.492	7.455	2.8477	2.2365	5.3014
3-4	10.21	8.018	3.0625	2.4053	5.4978
13-16	10.95	8.601	3.2852	2.5802	5.6941
7-8	11.72	9.204	3.5156	2.7612	5.8905
15-16	12.51	9.828	3.7539	2.9483	6.0868
2	13.33	10.47	4.0000	3.1416	6.2832
1-16	14.18	11.14	4.2539	3.3410	6.4795
1-8	15.05	11.82	4.5156	3.5466	6.6759
3-16	15.95	12.53	4.7852	3.7583	6.8722
1-4	16.88	13.25	5.0625	3.9761	7.0686
5-16	17.83	14.00	5.3477	4.2000	7.2649
3-8	18.80	14.77	5.6406	4.4301	7.4613
7-16	19.80	15.55	5.9414	4.6664	7.6576
1-2	20.83	16.36	6.2500	4.9087	7.8540
9-16	21.89	17.19	6.5664	5.1572	8.0503
5-8	22.97	18.04	6.8906	5.4119	8.2467

Thickness or diameter in inches.	Weight of □ bar one foot long.	Weight of ○ bar one foot long.	Area of □ bar in square inches.	Area of ○ bar in square inches.	Circumference of ○ bar in inches.
11-16	24.08	18.91	7.2227	5.6727	8.4430
3-4	25.21	19.80	7.5625	5.9396	8.6394
13-16	26.37	20.71	7.9102	6.2126	8.8357
7-8	27.55	21.64	8.2656	6.4918	9.0321
15-16	28.76	22.59	8.6289	6.7771	9.2284
3	30.00	23.56	9.0000	7.0686	9.4248
1-16	31.26	24.55	9.3789	7.3662	9.6211
1-8	32.55	25.57	9.7656	7.6699	9.8175
3-16	33.87	26.60	10.160	7.9798	10.014
1-4	35.21	27.65	10.563	8.2958	10.210
5-16	36.58	28.73	10.973	8.6179	10.407
3-8	37.97	29.82	11.391	8.9462	10.603
7-16	39.39	30.94	11.816	9.2806	10.799
1-2	40.83	32.07	12.250	9.6211	10.996
9-16	42.30	33.23	12.691	9.9678	11.192
5-8	43.80	34.40	13.141	10.321	11.388
11-16	45.33	35.60	13.598	10.680	11.585
3-4	46.88	36.82	14.063	11.045	11.781
13-16	48.45	38.05	14.535	11.416	11.977
7-8	50.05	39.31	15.016	11.793	12.174
15-16	51.68	40.59	15.504	12.177	12.370

WEIGHT OF A SQUARE FOOT OF VARIOUS METALS.

Thickness (in inches)	Wrought iron lbs.	Copper lbs.	Brass lbs.	Lead lbs.	Cast iron lbs.	Steel lbs.	Zinc lbs.
1-16	2.5	2.9	2.7	3.7	2.3	2.5	2.3
1-8	5.0	5.8	5.5	7.4	4.7	5.1	4.7
3-16	7.5	8.7	8.2	11.1	7.0	7.7	7.0
1-4	10.0	11.6	10.9	14.8	9.4	10.2	9.4
5-16	12.5	14.5	13.6	18.5	11.7	12.8	11.7
3-8	15.	17.4	16.3	22.2	14.1	15.3	14.1
7-16	17.5	20.3	19.0	25.9	16.4	17.9	16.4
1-2	20.	23.2	21.8	29.6	18.7	20.4	18.7
5-8	25.	28.9	27.1	37.0	23.4	25.5	23.4
3-4	30.	34.7	82.5	44.4	28.1	30.6	28.1
7-8	35.	40.4	37.9	57.8	32.8	35.7	32.8
1	40.	46.2	43.3	59.2	37.5	40.8	37.5

WEIGHT OF CASTINGS FROM PATTERNS.—BOLLAND.

A pattern weighing one pound made of	Will weigh when cast in				
	Cast iron lbs.	Zinc lbs.	Copper lbs.	Yellow brass lbs.	Gun metal lbs.
Mahogany—Nassau ...	10.7	10.4	12.8	12.2	12.5
" Honduras .	12.9	12.7	15.3	14.6	15.
" Spanish ...	8.5	8.2	10.1	9.7	9.9
Pine—Red	12.5	12.1	14.9	14.2	14.6
" White	16.7	16.1	19.8	19.	19.5
" Yellow	14.1	13.6	16.7	16.	16.5
Oak	9.	8.6	10.4	10.1	10.9

PRESSURES IN OUNCES PER SQUARE INCH CORRESPONDING TO VARIOUS HEADS OF WATER IN INCHES.

Head in inches.	Decimal parts of an inch.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0		0.06	0.12	0.17	0.23	0.29	0.35	0.40	0.46	0.52
1	0.58	0.63	0.69	0.75	0.81	0.87	0.93	0.98	1.04	1.09
2	1.16	1.21	1.27	1.33	1.39	1.44	1.50	1.56	1.62	1.67
3	1.73	1.79	1.85	1.91	1.96	2.02	2.08	2.14	2.19	2.25
4	2.31	2.37	2.42	2.48	2.54	2.60	2.66	2.72	2.77	2.83
5	2.89	2.94	3.00	3.06	3.12	3.18	3.24	3.29	3.35	3.41
6	3.47	3.52	3.58	3.64	3.70	3.75	3.81	3.87	3.92	3.98
7	4.04	4.10	4.16	4.22	4.28	4.33	4.39	4.45	4.50	4.56
8	4.62	4.67	4.73	4.79	4.85	4.91	4.97	5.03	5.08	5.14
9	5.20	5.26	5.31	5.37	5.42	5.48	5.54	5.60	5.66	5.72

DIFFERENT STANDARDS FOR WIRE GAGE IN USE IN THE UNITED STATES.

DIMENSIONS OF SIZES IN DECIMAL PARTS OF AN INCH.

Number of wire gage.	American or Brown & Sharpe.	Birmingham, or Stubs' wire.	Washburn & Moen Mfg. Co., Worcester, Mass.	Imperial wire gage.	Stubs' steel wire.	U. S. Stand. for plate.	Number of wire gage.
000000	.....	...	.....	.464	...	.46875	000000
00000	.....	...	.....	.432	...	.4375	00000
0000	.46	.454	.3938	.400	...	.40625	0000
000	.40964	.425	.3625	.372	...	.375	000
00	.3648	.38	.3310	.348	...	.34375	00
0	.32486	.34	.3065	.324	...	.3125	0

Number of wire gage.	American or Brown & Sharpe.	Birmingham or Stubs' wire.	Washburn & Moen Mfg. Co., Worcester, Mass.	Imperial wire gage.	Stubs' steel wire.	U. S. Stand. for plate.	Number of wire gage.
1	.2893	.3	.2830	.300	.227	.28125	1
2	.25763	.284	.2625	.276	.219	.265625	2
3	.22942	.259	.2437	.252	.212	.25	3
4	.20431	.238	.2253	.232	.207	.234375	4
5	.18194	.22	.2070	.212	.204	.21875	5
6	.16202	.203	.1920	.192	.201	.203125	6
7	.14428	.18	.1770	.176	.199	.1875	7
8	.12849	.165	.1620	.160	.197	.171875	8
9	.11443	.148	.1483	.144	.194	.15625	9
10	.10189	.134	.1350	.128	.191	.140625	10
11	.090742	.12	.1205	.116	.188	.125	11
12	.080808	.109	.1055	.104	.185	.109375	12
13	.071961	.095	.0915	.092	.182	.09375	13
14	.064084	.083	.0800	.080	.180	.078125	14
15	.057068	.072	.0720	.072	.178	.0703125	15
16	.05082	.065	.0625	.064	.175	.0625	16
17	.045257	.058	.0540	.056	.172	.05625	17
18	.040303	.049	.0475	.048	.168	.05	18
19	.03589	.042	.0410	.049	.164	.04375	19
20	.031961	.035	.0348	.036	.161	.0375	20
21	.028462	.032	.03175	.032	.157	.034375	21
22	.025347	.028	.0286	.028	.155	.03125	22
23	.022571	.025	.0258	.024	.153	.028125	23
24	.0201	.022	.0230	.022	.151	.025	24
25	.0179	.02	.0204	.020	.148	.021875	25
26	.01594	.018	.0181	.018	.146	.01875	26
27	.014195	.016	.0173	.0164	.143	.0171875	27
28	.012641	.014	.0162	.0149	.139	.015625	28
29	.011257	.013	.0150	.0136	.134	.0140625	29
30	.010025	.012	.0140	.0124	.127	.0125	30
31	.008928	.01	.0132	.0116	.120	.0109375	31
32	.00795	.009	.0128	.0108	.115	.01015625	32
33	.00708	.008	.0118	.0100	.112	.009375	33
34	.006304	.007	.0104	.0092	.110	.00859375	34
35	.005614	.005	.0095	.0084	.108	.0078125	35
36	.005	.004	.0090	.0076	.106	.00703125	36
37	.004453	...	....	.0068	.103	.006640625	37
38	.003965	...	....	.0060	.101	.00625	38
39	.003531	...	....	.0052	.099	.....	39
40	.003144	...	....	.0048	.097	.....	40

U. S. STANDARD SCREW THREADS.

Diameter of screw.	Threads per inch.	Diameter at root of thread.	Width of flat.
1-4	20	.185	.0063
5-16	18	.2403	.0069
3-8	16	.2936	.0078
7-16	14	.3447	.0089
1-2	13	.4001	.0096
9-16	12	.4542	.0104
5-8	11	.5069	.0114
3-4	10	.6201	.0125
7-8	9	.7307	.0139
1	8	.8376	.0156
1 1-8	7	.9394	.0179
1 1-4	7	1.0644	.0179
1 3-8	6	1.1585	.0208
1 1-2	6	1.2835	.0208
1 5-8	5 1-2	1.3888	.0227
1 3-4	5	1.4902	.0250
1 7-8	5	1.6152	.0250
2	4 1-2	1.7113	.0278
2 1-4	4 1-2	1.9613	.0278
2 1-2	4	2.1752	.0313
2 3-4	4	2.4252	.0313
3	3 1-2	2.6288	.0357
3 1-4	3 1-2	2.8788	.0357
3 1-2	3 1-4	3.1003	.0385
3 3-4	3	3.3170	.0417
4	3	3.5670	.0417
4 1-4	2 7-8	3.7982	.0435
4 1-2	2 3-4	4.0276	.0455
4 3-4	2 5-8	4.2551	.0476
5	2 1-2	4.4804	.0500
5 1-4	2 1-2	4.7304	.0500
5 1-2	2 3-8	4.9530	.0526
5 3-4	2 3-8	5.2030	.0526
6	2 1-4	5.4226	.0556

HYDRAULIC DATA.

TABLE OF GALLONS.

	Cub. ins. in a gallon	Wgt. of gal. pounds avoirdupois	Gallons in a cu. ft.	One cub. ft. of water at its maximum density 39.1° Fahr. weighs 62.425 lbs. Avoirdupois.
United States..	231	8.33	7.480	
Imperial.....	277.274	10.00	6.242	

One Imperial gallon..... = 1.2 U. S. gallons.
One U. S. gallon..... = 0.833 Imperial gallons.
268.8 U. S. gallons of water..... = 1 ton.
35.88 cubic feet of water..... = 1 ton.
1 cubic inch of water..... = .03613 pounds.
Cubic feet of water x 62.425..... = pounds.
Cubic inches of water x .03613..... = pounds.
U. S. gallons x .13368..... = cubic feet.
Cubic inches x .004329..... = U. S. gallons.
Cubic feet x 7.48..... = U. S. gallons.
Cubic inches x .0005787..... = cubic feet.
Pressure of a water column in pounds per square inch..... = height of column in feet x .4335.
Pressure of a water column in pounds per square foot..... = height of column in feet x 62.425.
One cu. ft. sea water at 62° Fahr... = 64 pounds.
One cu. in. sea water..... = 0.037037 pounds.

TABLE OF DIMENSIONS OF STANDARD WEIGHT WROUGHT-IRON PIPE.

ONE AND ONE-QUARTER AND SMALLER PROVED TO 300 POUNDS PER SQUARE INCH BY HYDRAULIC PRESSURE. ONE AND ONE-HALF AND LARGER PROVED TO 500 POUNDS PER SQUARE INCH BY HYDRAULIC PRESSURE.

Inside Diameter	Actual Outside Diameter	Thickness	Actual Inside Diameter	Inside Circumference	Outside Circumference	Length of Pipe per square foot of inside surface	Length of Pipe per square foot of outside surface	Inside Area	Outside Area	Length of Pipe containing one cubic foot	Weight per foot	No. of Threads per inch of screw	Taper of Threads per inch of screw
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Feet.	Feet.	Ins.	Ins.	Feet.	Lbs.		In.
1/8	0.405	0.068	0.270	0.848	1.272	14.15	9.44	0.0572	0.129	2500.	0.243	27	1-32
1/4	0.54	0.088	0.364	1.144	1.696	10.50	7.075	0.1041	0.229	1385.	0.422	18	1-32
3/8	0.675	0.091	0.494	1.552	2.121	7.67	5.657	0.1916	0.358	751.5	0.561	18	1-32
1/2	0.84	0.109	0.623	1.957	2.652	6.13	4.502	0.3048	0.554	472.4	0.845	14	1-32
3/4	1.05	0.113	0.824	2.589	3.299	4.635	3.637	0.5333	0.866	270.	1.126	14	1-32
1	1.315	0.134	1.048	3.292	4.134	3.679	2.903	0.8627	1.357	166.9	1.670	11½	1-32
1 1/4	1.66	0.140	1.380	4.335	5.215	2.768	2.301	1.496	2.164	96.25	2.258	11½	1-32
1 1/2	1.90	0.145	1.611	5.061	5.969	2.371	2.01	2.038	2.835	70.65	2.694	11½	1-32
2	2.375	0.154	2.067	6.494	7.461	1.848	1.611	3.355	4.430	42.36	3.600	11½	1-32
2 1/2	2.875	0.204	2.468	7.754	9.032	1.547	1.328	4.783	6.491	30.11	5.773	8	1-32
3	3.50	0.217	3.067	9.636	10.996	1.245	1.091	7.388	9.621	19.49	7.547	8	1-32
3 1/2	4.00	0.226	3.548	11.146	12.566	1.077	0.955	9.887	12.566	14.56	9.055	8	1-32
4	4.50	0.237	4.026	12.648	14.137	0.949	0.849	12.730	15.904	11.31	10.66	8	1-32
4 1/2	5.00	0.247	4.508	14.153	15.708	0.848	0.765	15.939	19.635	9.03	12.34	8	1-32
5	5.563	0.259	5.045	15.849	17.475	0.757	0.629	19.990	24.299	7.20	14.50	8	1-32
6	6.625	0.280	6.065	19.054	20.813	0.63	0.577	28.889	34.471	4.98	18.767	8	1-32
7	7.625	0.301	7.023	22.063	23.954	0.544	0.595	38.737	45.663	3.72	23.27	8	1-32
8	8.625	0.322	7.982	25.076	27.096	0.478	0.444	50.039	58.426	2.88	28.177	8	1-32
9	9.625	0.344	9.001	28.277	30.433	0.425	0.394	63.633	73.715	2.26	33.70	8	1-64
10	10.75	0.366	10.019	31.475	33.772	0.381	0.355	78.838	90.762	1.80	40.06	8	1-64
11	12.00	0.375	11.25	35.343	37.699	0.340	0.318	98.942	113.097	1.455	45.95	8	1-64
12	12.75	0.375	12.000	38.264	40.840	0.313	0.293	116.535	132.732	1.235	48.98	8	1-64
13	14.00	0.375	13.25	41.268	43.982	0.290	0.273	134.582	153.938	1.069	53.92	8	1-64
14	15.00	0.375	14.25	44.271	47.124	0.271	0.254	155.968	176.715	.923	57.89	8	1-64
—	16.00	0.375	15.25	47.274	50.265	0.254	0.238	177.867	201.062	.809	61.77	8	1-64
—	18.00	0.375	17.25	53.281	56.548	0.225	0.212	225.907	254.469	.638	69.66	—	—
—	20.00	0.375	19.25	59.288	62.832	0.202	0.191	279.720	314.160	.515	77.57	—	—
—	22.00	0.375	21.25	66.759	69.115	0.179	0.174	354.66	380.134	.406	85.47	—	—
—	24.00	0.375	23.25	73.04	75.39	0.164	0.159	424.56	452.39	.339	93.37	—	—

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